SOLAR ENERGY FOR THE
NAVAL SHORE ESTABLISHMENT.

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

SOLAR ENERGY
FOR THE
NAVAL SHORE ESTABLISHMENT

by

Bruce Burgee Geibel

December 1977

Thesis Co-Advisors: J. W. Creighton
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This thesis discusses the background and extent of the current national energy crisis, and reviews the alternative energy sources available to the United States Navy other than conventional fossil fuels. An in-depth analysis is made of the advantages, disadvantages and techniques of one of these alternatives, solar energy conversion. The National Solar Energy Program is reviewed, as is the role of the Department of Defense and the United States Navy in this program. Methods of "retrofitting" existing

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20. (continued)

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Solar Energy for the Naval Shore Establishment

by

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Submitted in partial fulfillment of the
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This thesis discusses the background and extent of the current national energy crisis, and reviews the alternative energy sources available to the United States Navy other than conventional fossil fuels. An in-depth analysis is made of the advantages, disadvantages and techniques of one of these alternatives, solar energy conversion. The National Solar Energy Program is reviewed, as is the role of the Department of Defense and the United States Navy in this program. Methods of "retrofitting" existing Navy facilities with solar energy systems are discussed, as are new construction techniques. The thesis further contains techniques for life-cycle costing of alternative solar energy systems, which includes computer model programs such as BASIC Language, F-Chart calculations, and SOLCOST calculations. The thesis concludes with suggestions for establishing a viable solar energy program on an activity or individual basis. A comprehensive reference list and bibliography is provided to identify where technical and engineering details can be found.

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FOREWORD

Energy is defined in classical thermodynamics as the capacity to do work. From a practical point of view it is the basic ingredient for all industrialized societies. In the United States energy is currently derived from four primary sources: petroleum, natural gas and natural gas liquids, coal and wood. The supplies of these common energy sources, except for wood, are finite. Their lifetime is estimated to range from 15 years for natural gas to 300 years for coal. As current energy sources become exhausted an energy gap will develop, exacerbated by the synergistic effects of population growth and increased dependence on energy. After nonrenewable energy sources are consumed in what some authors call the "Fossil Fuel Age," mankind must turn to longer-term, permanent energy sources. Nuclear energy requires highly technical and costly means for its safe and reliable utilization and may have undesirable side-effects. Solar energy, on the other hand, shows promise of becoming a dependable energy source without new requirements of a highly technical and specialized nature for its widespread utilization.

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I. INTRODUCTION

> For generations, Americans have viewed cheap and plentiful energy as their birthright. Coal, oil or gas have always been abundantly available to heat our homes, power our automobiles, and fuel our industries. But just as the supply of these fossil fuels begins to dwindle and we look to the atom for salvation, we are beginning to perceive the environmental havoc being wrought by our indiscriminate use of energy. Our urban and suburban skies are choked with smog; our rivers and shores are streaked with oil; even the food we eat and the water we drink are suspect. And while promising us temporary relief from energy starvation, nuclear power threatens a new round of pollution whose severity is still a matter of speculation.
>
> (Bruce Anderson) [Ref. 26].

It is extremely difficult today to pick up a newspaper or magazine, listen to the radio or watch television, and not read about or listen to the national debate on the hottest issue of our time -- the "energy crisis" that looms over every man, woman and child in this nation. As with the rest of the Nation, the Department of Defense (DOD) and the Department of the Navy face continuing serious energy problems involving: (1) dependence on diminishing petroleum supplies -- natural gas and oil; (2) dependence on increasing amounts of imported oil -- the nation now imports between 45-50% of its petroleum needs [Refs. 83, 87]; (3) an extended period of increasingly costly energy sources; and (4) a massive research, development, and demonstration (RD&D) program aimed at locating and using alternative energy sources in the future.

The Navy is in a unique position to make a major contribution to the Nation's energy programs now underway. The typical naval complex is in essence a microcosm of the energy consuming public in that all the essentials of the residential, industrial, commercial, and transportation sectors are represented. At many of these complexes, the Navy is also a producer of energy, thus providing a great deal of flexibility and diversity of options in coping with the energy production, distribution, and consumption problems normally associated with a typical small American city. However, there is one slight difference. Many of the Navy's bases are located overseas at remote and foreign sites in support of the Navy's "forward deployment" base concept. These locations depend almost entirely on the local sources of energy.

Because so many of the Navy's operations are conducted overseas and on the "high seas" deployed to strategic locations around the world, the logistics system depends heavily on petroleum purchases and sources located overseas. Typically, DOD consumes about 3.3% of the Nation's total energy. However, 72% of DOD's demand is for petroleum alone. This is significant when one considers that up to 50% of the Nation's and DOD's petroleum is purchased from overseas sources. The Navy's share of DOD's consumption is about 35.8% -- compared to the Air Force with 54.6% and the Army with 9.6%. This makes the Navy highly dependent on foreign oil sources with all their political and economical ramifications. These statistics are based on

Fiscal Year 1974 (FY74) data. See Appendix A for additional information. [Refs. 2, 3].

This dependence on foreign oil has always represented a vulnerability to the Navy. But, in late 1973 the Navy, for the first time, encountered obstacles to making foreign purchases of petroleum and in gaining access to petroleum stocks located in friendly foreign countries.

> These constraints had, in this case, no apparent effect on the ability of the U.S. to carry out the desired operations; however, increased domestic petroleum purchases compounded the jet fuel shortages in the U.S. The changed overseas situation has caused a reassessment of logistic support needs, particularly as to maintenance of war reserve stocks. [Ref. 3].

The 1973-74 Arab oil embargo only highlighted how vulnerable the Nation and the Navy could be through extended energy supply disruptions. Yet, the total fossil fuel energy demand forecast into the 21st Century by various energy scenarios indicates increasing dependence on imported fuels at ever increasing prices. To compound the situation, the Navy has recently been forced to cut back on its nuclear powered fleet. Since no political action or technological development that would relieve the Navy from complete dependence on imported oil is anticipated, the Navy must develop either "new" domestic energy sources of oil and petroleum or alternative sources of energy such as solar energy, geothermal energy, or nuclear energy.

A Department of Energy, combining many of the federal functions relating to energy into a single agency, has been recently established by Congress with former Defense Secretary James R. Schlesinger at

the helm. It began operation on 1 October 1977, the start date of the Government's new Fiscal Year 1978. (FY78). The Act creating the Department of Energy (DOE) transfers from the Navy to DOE administration of, and jurisdiction over, three designated naval petroleum reserves and three oil-shale reserves located in the lower 48 states. [Ref. 81] This in effect took away some of the Navy's control over their strategic oil reserves. The result is that it is becoming increasingly important for the Navy to develop alternative sources of energy in the future to supplement diminishing and uncontrollable quantities of oil and petroleum.

A combination of these situations has motivated the Navy to establish an energy research, development and demonstration (RD&D) effort -- in support of DOD -- to reduce consumption of energy, evolve power systems capable of utilizing alternative energy sources, and supplement the dwindling fossil fuel sources. The Navy is developing new energy technology in order to achieve its three primary goals: (1) conservation;* (2) energy self-sufficiency; and (3) the utilization of synthetic fuels. These goals will be discussed in more detail in Chapter VI. [Ref. 1].

A. PROBLEM ADDRESSED

> The diagnosis of the U. S. energy crisis is quite simple: demand for energy is increasing, while supplies of oil and natural gas are diminishing. Unless the U.S. makes a timely adjustment before world oil becomes very scarce and very expensive in the 1980's, the nation's economic security and

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*An overall conservation goal for all Federal agencies and departments was established as 15% over a 1973 base-line energy consumption by Federal Management Circular FMC 74-1, 15 November 1974.

> the American way of life will be gravely endangered. The steps the U.S. must take now are small compared to the drastic measures that will be needed if the U.S. does nothing until it is too late. [Ref. 7].

The current rapidly expanding National energy program presents the Navy with a myriad of different concerns evolving around two basic interrelated issues. One, it is endangering the environment with by-products of an affluent and technologically-oriented organization. Two, it is quickly exhausting its fossil fuel sources. New, virtually inexhaustible, and environmentally clean sources of energy are needed to insure that the Navy is able to maintain its technological advantages and superiority, and to enable it to continue the important role it plays in our Nation's defense.

B. APPROACH

The approach in this thesis will be one of: (1) looking at the overall picture of the "energy crisis" facing the Navy; (2) researching various available options to help overcome this "energy crisis;" (3) collecting and presenting the material scattered (and often hidden) in many sources; (4) summarizing the work of a very large number of research workers in a systematic form; and (5) giving a conceptual understanding of the problems and the solutions and thus, by describing what has been done, help to generate new ideas.

This thesis is divided into nine chapters. Chapter I is the introductory chapter. Chapter II discusses the fossil fuel dilemma facing

the nation, and discusses the origin of fossil fuels describing what makes them so finite and non-renewable. The availability of fossil fuels and the Nation's present consumption rate is also discussed, as well as the significant role that natural gas plays in the Nation's energy future. Chapter III looks at the fundamental aspects of solar energy, e.g., solar radiation (insolation), availability, advantages, disadvantages, components, economics, operation, and types. Chapter IV looks at various applications of solar energy, such as space heating and cooling, water heating, photovoltaic (solar cell) uses, waterpower, wind generation, etc.

Chapter V looks at solar energy as a viable part of the national energy program and discusses various Federal and State Laws that govern the development of solar energy systems in the future. A brief history of solar energy development leading up to the formulation of the national energy program is also given. Chapter VI discusses the Department of Defense and Department of the Navy role in the nation's solar energy program.

Chapter VII discusses techniques for retrofitting existing buildings with solar energy systems and Chapter VIII discusses the utilization of solar energy systems in construction of new facilities. Chapter IX summarizes the major conclusions reached in this thesis and concludes with recommendations for a Navy solar energy program. Techniques

for life-cycle costing analysis of alternative energy systems for comparison with fossil fuel sources is included as Appendix B, along with a computer program format for economical evaluation written in BASIC Language and examples of F-Chart and SOLCOST methods of economic analysis, contained in Appendix C. A comprehensive reference list and bibliography is provided throughout to identify where additional technical and engineering details on solar energy systems can be found.

II. THE NEED FOR ALTERNATIVE ENERGY SOURCES

A. FOSSIL FUEL DILEMMA

Chancey Starr, Dean of the School of Engineering and Applied Science, University of California at Los Angeles, places the current fossil fuel dilemma in the following perspective:

> _ Between now, and (the year) 2001, just (24) years away, the U.S. will consume more energy than it has in its entire history. By 2001 the annual U.S. demand for energy in all forms is expected to double and the annual worldwide demand will probably triple. These projected increases will tax man's ability to discover, extract, and refine fuels in the huge volumes necessary, to ship them safely, to find suitable locations for several hundred new electric-power stations in the U.S. (thousands worldwide) and to dispose of effluents and waste products with minimum harm to himself and his environment. ... The energy projections for 2001 indicate the need for careful planning of our future course. We shall have to examine with both objectivity and humanity the necessity for our projected increase in energy demand, its relation to our quality of life, the practical options technology provides for meeting our needs and the environmental and social consequences of these options.
>
> (Chancey Starr) [Ref. 9].

The United States, with about 6% of the world's population, consumes about 35% of the world's total energy. This is a flagrantly skewed level of consumption causing other countries, and many people in our own country, to call for a more balanced energy consumption rate. This Nation has literally been developed, without significant restrictions due to any lack of energy resources, because our energy resources have heretofore been considered to be in ample supply.

However, we now see ever increasing indications of the finite nature of fossil fuels and the fact that the U.S. cannot long maintain its exponential growth rate without major changes in energy supply patterns and lifestyles.*

1. Origin of Fossil Fuels

The world's supply of fossil fuels is not only finite but it is non-renewable and diminishing at a far greater rate than it took to make them. Necessary to the understanding of this finite (or diminishing) nature is the understanding of the origin of fossil fuels. Their origin dates back to the very creation of this planet and is involved with the geological process that accounted for the development of our present atmosphere as well as life itself.

> These processes occurred three billion years ago. At this time it is believed that the atmosphere was composed of water vapor, hydrogen gas, ammonia and methane. It is further speculated that an external energy source such as an electrical spark in the presence of ultraviolet light caused the first living cell to be synthesized.
>
> The first metabolic process was fermentation. One of its major metabolic by-products, carbon dioxide, increased in sufficient quantity to disrupt the electromagnetic radiation incident to the earth. Because carbon dioxide is opaque to infrared radiation (heat or longwave radiation), it acts as an

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*For further information on the finite and diminishing nature of our fossil fuels, the following references are recommended: Pazik, G., "Our Petroleum Predicament," Fishing Facts Magazine, p. 2-4, November 1976; Mitchell, E. J., U.S. Energy Policy : A Primer, The American Enterprise Institute for Public Policy Research, June 1974, Third Printing, April 1976; and The National Energy Plan, Executive Office of the President, Energy Policy and Planning, 20 April 1977.

insulator. The majority of radiation striking the earth is shortwave radiation. Much of it is reradiated as longwave radiation after it strikes the earth. The carbon dioxide blocks its passage and the resulting effect, often referred to as the Greenhouse Effect, is an increase in the ambient temperature of the earth's surface. This occurrence set the stage for the second and perhaps most important process, photosynthesis, to occur, first in an aquatic environment and later in a terrestrial environment.

Photosynthesis is the process that provides for the sun to be the ultimate source of all energy on earth. In this process, the radiant energy of the sun is transferred to chemical energy and stored in organic matter. A by-product of this process is oxygen. In order for oxygen to have accumulated in the atmosphere, much of the organic matter resulting from photosynthesis had to be sequestered to prevent respiration processes (the reverse of photosynthesis) from consuming it, and in so doing, using up all the oxygen generated. This organic matter slowly became locked in the earth's crust and was geologically transformed to our fossil fuels of today.

Finally, as oxygen built up in the atmosphere some of it was converted to ozone and formed an upper atmosphere layer. Because ozone absorbs damaging shortwave ultraviolet radiation, this action set the stage for the evolution of life as we know it.* (Marshall W. Nay, Jr.) [Ref. 10].

The processes described in the preceding paragraphs are not occurring today. It is for this reason that fossil fuels are considered to be <u>finite</u> and <u>non-renewable</u>. There simply isn't time to remake these fossil fuels -- at least in our lifetime, or any foreseeable lifetime.

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*For further information on this process, the following references are recommended: Commoner, B., <u>The Closing Circle</u>, Alfred A. Knoph, New York, p. 17-21, 29-30, 1971; and Cloud, P. and Gibor, A., "The Oxygen Circle," <u>The Biosphere, Scientific American</u>, Freeman and Co., p. 68, 1970.

2. Availability of Fossil Fuels

Numerous energy scenarios and some rather sophisticated graphs, charts and models have been developed during the past decade or more all extolling the availability of fossil fuels now and in the future. The Hubbert Curves (named after Dr. M. King Hubbert, world renowned geophysicist of the Department of the Interior) indicate that U.S. production of crude oil and natural gas peaked in the early 1970s, and that production from the vast Middle East oil fields will pass its peak in the last decade of this century. [Ref. 11, 12]. Dr. Hubbert has remarked "... that a child born during the 1930s will probably live long enough to see the United States consume most of its oil reserves ..." [Ref. 13].

A few statistics are furnished for background information on the estimated remaining fossil fuel supplies available to the world. Table I is an estimate of the world supply of fossil fuels. How much of it is economically recoverable is, of course, subject to much conjecture, and will depend primarily on future technologies.

Table I. Estimated World Conventional Fossil Fuel Supplies

Type	Quantity	Conversion	Q(10^{18} Btu)	%
Coal	7500 billion tons	26.3×10^6 Btu/ton	197.3	95.0
Oil	1700 billion barrels	5.5×10^6 Btu/barrel	9.4	4.5
Gas	900 trillion cu. ft.	1030 Btu/ft^3	0.9	0.5
			207.6	100.0

(Source: Ref. 10).

Perhaps even more important than the quantity of supplies available is the location of proven/potential reserves, in particular quantities of petroleum, since during 1974, 19% of our nation's energy requirements were supplied by imports, and just about all of it, over 93%, was imported petroleum. [Ref. 15]. Table II is an estimate of proven/potential world petroleum reserves. It should be noted that 32.9% and 26.7% of the reserves are located in and/or controlled by Middle East and Communist Bloc countries respectively.

Table II. Estimated World Petroleum Reserves

Country/Area	Quantity (Billion barrels)	Percent
Canada	78	4.6
United States	127	7.5
Latin America	130	7.6
Western Europe	66	3.9
Africa	147	8.6
Antarctica	20	1.2
Middle East	561	32.9
Communist Bloc	454	26.7
Far East	120	7.0
Total:	1703	100.0

(Source: Ref. 10).

According to Mr. George Pazik, Editor and Publisher of Fishing Facts Magazine, the world's energy supplies are indeed peaking out. Several conclusions he has reached in a special energy editorial

are: (1) about 80% of the oil that will ever be produced from the lower 48 states had already been discovered by 1971; (2) the U.S. is importing a little over 40% (current studies indicate 45-50%) of its oil needs from abroad; (3) the U.S. has less than 5% of the world's known crude oil reserves (slightly different from the 7.5% figure in Table II); (4) the U.S. is using oil faster and in more significant quantities than any other nation in the world -- guess who will run out first? (5) U.S. natural gas production peaked in 1973 and has been diminishing ever since; (6) natural gas is already in such short supply that it is no longer a question if some users will be cut off, but only who will be first and second; (7) those who believe that some miracle of technology is going to magically appear to produce a cheap, simple substitute for petroleum are probably "... the same people who still believe that storks bring babies." [Ref. 12]

3. United States Energy Consumption

Despite the appearance that the U.S. consumes energy far more lavishly than other nations of the world, only about 4% of its gross national product (GNP) was spent on energy in 1973. At the same time, most Western European nations were spending between 8-12% of their GNPs for energy. On the surface, at least, the U.S. does not appear to be too gluttonous in its energy consumption. Figure 1 illustrates how this energy consumption breaks down into specific U.S. energy use categories. [Ref. 11]

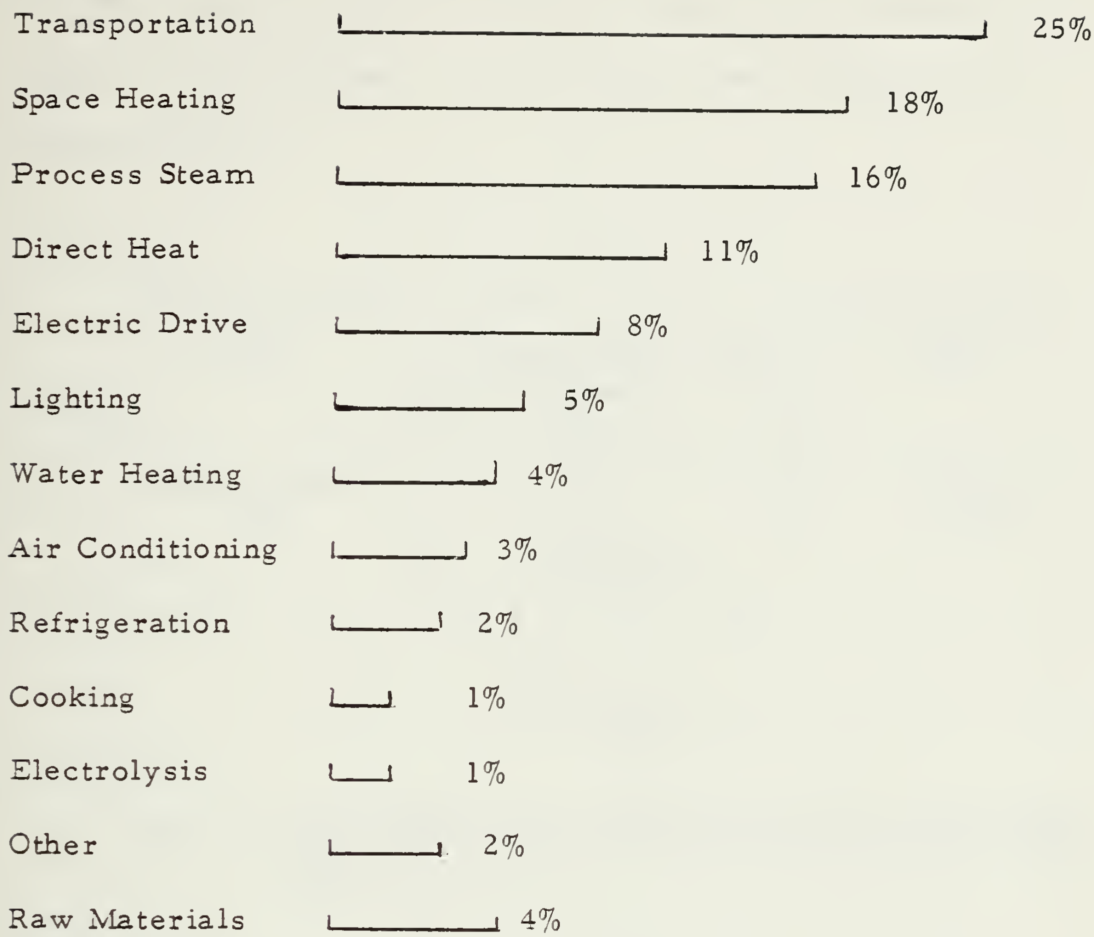


Fig. 1. Percentage of U.S. Energy Use
(Source: Ref. 11).

Energy consumption in the U.S. falls into four major categories: (1) residential (19%); (2) transportation (24%); (3) commercial (14%); and (4) industrial (43%). Figure 2 illustrates this breakdown. Clearly, it is the business community that has the largest stake in our nation's energy future -- 70% of the total energy consumption. Therefore, the business community will have to recognize their stake and take appropriate measures to protect it -- business operations, employment, and the growth of the Nation's

GNP depend on it. But, the 30% consumed in the residential sector cannot be ignored either. It is this sector that touches every American's life.

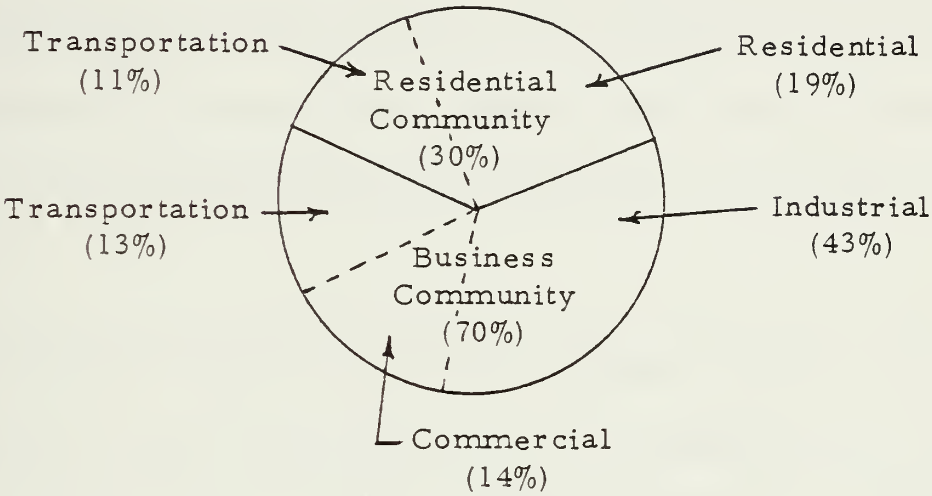


Fig. 2. U.S. Energy Consumption by Type of Application (Source: Ref. 17).

The Department of Defense is highly petroleum-intensive, with 72.5% of all energy coming from petroleum and 85.4% of that energy being consumed in ground, air and sea operations. However, energy use by DOD represents only 2.4% of the U.S. energy total and only 3.3% of the U.S. petroleum total.* Despite this relatively low overall energy consumption rate, as compared to the rest of the nation, DOD still manages to be highly visible to the public. This is

*DOD also consumes energy indirectly due to purchases of goods and services from the economy at large. If indirect sources were included, the percentages would become 4.1% and 4.8% respectively. Indirect uses amount to approximately 70% of direct use. (Source: Ref. 3).

primarily because 26% of the Nation's tax dollars (FY78 estimate) is spent on National Defense and DOD consumes over 72% of the total energy consumed by the Federal government (FY76 actual) [Refs. 4, 17, 72]. Because of this high public visibility placed on DOD, it is in a unique position to demonstrate to the nation that it can be energy consumption and cost conscious. Additional DOD energy consumption statistics can be found in Appendix A, Figures A-1, A-2, and A-3. [Ref. 3]

B. ALTERNATIVE ENERGY SYSTEM IMPLEMENTATION TIME

Another critical consideration in the development of additional fossil fuel sources is the project implementation time of various alternatives, Figure 3. As can be seen, it is not a simple matter to bring another generation or distribution system on the line.

TYPE OF ENERGY SYSTEM	IMPLEMENTATION TIME
Coal Fired Power Plant	5-8 Years
Surface Coal Mine	2-4 Years
Underground Coal Mine	3-5 Years
Uranium Exploration and Mine	7-10 Years
Nuclear Power Plant	9-10 Years
Hydroelectric Plant	5-8 Years
Produce Oil and Gas from New Field	3-10 Years
Produce Oil and Gas from Old Field	1-3 Years

Fig. 3. Typical Project Implementation Time (Source: Ref. 11).

Despite various available energy alternatives, natural gas has heretofore been considered the most popular source of space heating/cooling and water heating. It has been popular because of its low cost and its inherently clean characteristics. The reasons for its relative economy will be the subject of the next Section.

C. NATURAL GAS DILEMMA

Prior to WWII there was no economical way of transporting gas more than moderate distances away from the source. Markets were therefore confined to the immediate producing area. However, with the advent of large, new transportation systems in the early 1950s and enforcement of strict safety measures and Federal price regulations, natural gas usage quickly overtook coal as a prime source of energy. It eventually competed in popularity with oil and electricity.

A significant factor in the competitive advantage given to natural gas was the institution of Government price regulations. In 1953, the Supreme Court ordered the Federal Power Commission (FPC) to regulate the wellhead price of natural gas sold in the interstate commerce market restricting its price to actual production costs. The effect of this regulation was to maintain the price of gas at a disproportionately low rate for the next two decades -- 1953 to 1973 -- and to discourage the development of new domestic gas supplies. The FPC in 1974 allowed the price of all gas sold across state lines

to increase from an average of $0.23 to $0.42 per thousand cubic feet (Mcf), but, on a Btu basis, the new price was still equivalent to oil at $2.35 a barrel at a time when the average price of domestic oil was $7.00 a barrel and the world price was $10.00 a barrel and rising. [Ref. 11]

The low ceiling price on gas increased demand and stimulated production out of existing U.S. reserves -- it was hardly worthwhile to hold these huge reserves for production at a later date if prices were not going to rise. A shortage of natural gas supplies was occurring before our very eyes and would soon come to a head in the mid-1970s. According to Edward J. Mitchell, professor of business economics at the University of Michigan, ...

> The shortage of energy now facing the nation is not a problem for public policy -- it is a public policy. Shortages can be eliminated very simply: remove the price controls on energy .... The only economical way out of the present energy dilemma is to allow energy markets to clear. If a free-market policy is not adopted, the shortages will tend to grow larger and supplies will dwindle. .... [Ref. 13].

Further support of deregulation of natural gas and other fossil fuel energy prices has been succinctly put by Professor Milton Friedman, Nobel prize-winning economist and the world's leading monetary theorist:

> Economists may not know much. But we do know one thing very well: how to produce shortages and surpluses. Do you want to produce a shortage of any product? Simply have government fix and enforce a

> legal MAXIMUM price on the product which is less than the price that would otherwise prevail ... Do you want to produce a surplus of any product? Simply have government fix and enforce a legal MINIMUM price above the price that would otherwise prevail. [Ref. 13].

At the present time President Carter and Congress are engaged in a struggle over natural gas deregulation options. The President is calling on Congress to legislate on a rational pricing policy accordingly:

> We can never increase our production of oil and natural gas by enough to meet our demand, but we must be sure that our pricing system is sensible, discourages waste and encourages exploration and new production. One of the principles of our energy policy is that the price of energy should reflect its true replacement cost, as a means of bringing supply and demand into balance over the long-run. Realistic pricing is especially important for our scarcest fuels, oil and natural gas. [Ref. 18].

On the other hand, there are some factions in Congress that are calling for the complete deregulation of natural gas prices. And, in January 1977, the Energy Research and Development Administration (ERDA) put together a study group called the Market Oriented Program Planning Study (MOPPS) which came up with some rather startling information (or conjecture). The study, according to the Wall Street Journal, estimated that at $2.25 per Mcf the nation would be awash in natural gas; from $2.50 to $3.00 per Mcf it would be engulfed with it; and MOPPS suggested that at $2.50 per Mcf the nation would have about 45-years worth of natural gas left at current levels of consumption. [Ref. 41].

One can argue the merits or demerits of each of the various energy scenarios and quantity projections -- it is certainly a matter of conjecture. However, the ultimate quantity of natural gas or oil under the ground is (as Professor M. A. Adelman tells us) "... unknown, unknowable, and most important, uninteresting." [Ref. 13]. The more pertinent questions that must be asked are: (1) "How much do we have to give up to get that extra Mcf of gas or barrel of oil?" and (2) "How much is that extra Mcf of gas or barrel of oil worth to us?" If it is worth more than it costs, and if costs less than the alternative sources of energy available, we should use it; if not, we should simply leave the oil and gas in the ground and use the alternative sources of energy that are available.

D. ALTERNATIVE ENERGY SOURCES

> It is clear that the world's supply of .... precious natural resources will be exhausted in another 75 years, more or less. There won't be any more. What then? Better yet, what now, while we still have a little time? (Ralph J. Johnson) [Ref. 84].

The answer to this question lies in shifting, at least in part, from use of fossil fuels to alternative non-fossil fuels. It is apparent that the U.S. has the technology to do so. In many cases, the technology is available today. Some of these alternatives are nuclear-fusion, geothermal energy, organic waste bio-conversion, photo-voltaic (solar cell) power, hydroelectric power, ocean thermal, wind

generation, and solar energy. Today they all cost more than energy derived from fossil fuels. However, through more extensive research, development and demonstration (RD&D) efforts their costs can be reduced, and if fossil fuel prices continue to rise at current exorbitant rates, this cost problem may automatically correct itself.

President Carter fairly well outlined his plan for the Nation's energy policy and objectives in the National Energy Plan submitted to Congress for approval. According to this plan which will be discussed in more detail in Chapter V, the U.S. has three overriding energy objectives:

-- as an immediate objective to reduce dependence on foreign sources of energy and vulnerability to supply interruptions.

-- in the medium term, to keep U.S. imports sufficiently low to weather the period when world oil production approaches its capacity limitation.

-- in the long term, to have renewable and essentially inexhaustible sources of energy for sustaining economic growth. [Ref. 7].

Several of these alternative energy sources which are renewable and essentially inexhaustible are discussed below.

1. Waterpower

Although hydroelectric power supplies only about 4% of the total U.S. energy needs, it is generally considered as an advanced, mature industry. Only about 22% of available waterpower is utilized in the U.S. Waterpower is continuously resupplied by the sun, except

under severe drought conditions. Waterpower is more concentrated than solar power and can be stored in large reservoirs. Hydroelectric conversion approaches 80% efficiency, whereas efficiency in coal or fuel oil systems is only about 33%. If efficiency alone determined the success of an energy system, hydroelectricity would certainly rank among the very top. [Refs. 11, 52].

2. Tidal/Ocean Power

The tides and temperature differences in the ocean could make a modest contribution to U.S. electrical requirements. The total tidal power of the earth has been estimated at 1.4 billion kilowatts of which 1.1 billion kilowatts could be captured in bays and estuaries. Although it appears that tidal power could be significant it is doubtful that much of it will be harnessed for either economic or environmental reasons. Location is another critical factor. In the U.S., for example, only the Northeast and Alaska have tidal ranges sufficient to be of interest. Ocean currents offer a real potential energy source and the technology for converting this energy resource is probably available. However, it has not become a commercial reality except in a few areas of the world, e.g., France, the Soviet Union, and the People's Republic of China. The main barrier in use of ocean currents is that the capital investment needed is prohibitive relative to the value of the energy output. [Refs. 52, 106].

3. Geothermal Energy

A limited number of sites exist in the continental U. S. with geothermal resources, which, though not remote, appear sufficiently important to be considered a national energy asset. Such is the Coso Thermal Area where all the near surface activity lies wholly aboard the Naval Weapons Center, China Lake, California. Experts on geothermal deposits have predicted capacities as high as 1,000 megawatts for the area. There are a number of other U. S. sites located in Guam, Alaska and Hawaii where there is a vast potential for geothermal use. Geothermal energy is one of the major emphases in the National Energy Plan proposed by President Carter. High costs for RD&D efforts and corrosion are two of the major problems in the harnessing of geothermal energy. Corrosion studies at the Coso Geothermal area seek to determine the effects of various types of geothermal emissions on materials of construction. [Ref. 1].

4. Wind Generation

Wind is one of the largest solar derivatives behind the use of collectors to capture the sun's energy and energy contained in the oceans. Its use is "environmentally more benign" than fresh-water power, because no dams or land floodings are involved. Unfortunately, the bulk of wind power lies in the upper troposphere and the lower stratosphere and is not accessible to present-day technologies. However, there are earth land-masses in the U. S. where strong

surface winds are available -- e.g., the Aleutian Chain, the Great Plains, and portions of the East and West coasts. [Ref. 52].

Systems to draw power played an important role in providing energy to mankind until the last 100 years. Wind energy is ubiquitous and free. Much use was made of windmills over the past 2,000 years, or more, and wind use for pushing ships and drying clothes dates back much further than that. The exact date of the invention of the windmill for land use is uncertain, but vertical-axis machines have been capturing energy from the Persian winds since the first millenium A.D. Windmills as large as 16-foot long and 30-foot high were first devised to grind grain. The western world didn't discover windmills until much later. The earliest written references date the windmill in France in 1105 A.D. and in England in 1191 A.D. Since that time they have spread to the Netherlands, Germany, Denmark, and other countries of the world. The familiar multi-vane fan -- the farm windmill of the American West and Mid-West -- was invented in the U.S. in the latter half of the 19th Century and has since spread throughout the world. It is estimated that over six-million windmills (of less than 1-Hp) have been built and used in the U.S. since the mid-19th Century to pump water and generate electricity and that as many as 150,000 may still be in operation today. [Refs. 49, 51].

A 100-Kw wind generating machine near Sanduski, Ohio, is the world's largest wind machine in operation. [Ref. 49]. Another

large wind machine will be built atop a mountain near Boone, N.C., to test a method of supplying wind-driven energy. It has two slender rotors, each 100 foot long and together spanning 200 feet -- comparing to the wingspan of a Boeing Co. 747 jumbo jet. It is designed to generate 2,000 kilowatts of electric power in a 24-Mph wind -- enough to supply the power needs of more than 500 homes. [Ref. 107]. The program manager of NASA's wind power effort says wind energy may eventually provide 5-10% of the total U.S. electrical demand. [Ref. 49]. Operational data on a wind generator's performance for space heating applications will be collected by the U. S. Navy through extensive field testing at a semi-remote hilltop site at Laguna Peak, located about 15 miles from Port Hueneme, California. [Ref. 1]. A 10-Kw wind generator at another Navy site will be used to develop additional hardware required for using wind energy to:

a. Heat water for a storage rank using an immersion-type electric heater.

b. Operate a fan for attic fan.

c. Illuminate buildings using fluorescent tubes.

d. Operate a constant-speed heat pump.

The Navy Civil Engineering Laboratory (CEL) estimates that wind generators could supply 10% of the total Navy shore facility energy demand and eventually save the same percentage in utility costs. The total Navy shore facility energy bill in FY75 was $321

million, so a 10% reduction could amount to $32 million annually, without any escalation factor. Further proof-of-concept experimentation must be conducted before any large-scale use of the wind's energy can be adopted. [Ref. 1].

5. Solar Energy

> Mankind will require as much energy in the next 25 years as has been consumed in all of recorded history. As conventional fuels dwindle, solar energy presents itself as a virtually unlimited power source.
> (David F. Salisbury) [Ref. 108].

Small, direct uses of solar energy have been made over the years, but none on a scale which would sustain the substantial new industry required to develop solar energy systems to maintain our Nation's economic growth in the future. Scientists, engineers, and innovators have, in the last 5 years since the Arab oil embargo in 1973, begun to think beyond the small-scale uses to the large-scale uses of solar energy for heating and cooling, water heating, and power generation. Solar energy has its advantages of being readily available, clean, and virtually inexhaustible. For these reasons, and the fact that a large-scale National Solar Energy Program is being developed in the U.S. for research, development, and demonstration (RD&D) of potential alternative energy sources, which includes solar energy, the remainder of this thesis will concentrate on various aspects and applications of solar energy.

III. FUNDAMENTAL ASPECTS OF SOLAR ENERGY

> It is a human tendency to be uneasy with those things with which we are not entirely familiar.
> (Dr. Charles F. Westin)

A. HISTORICAL PERSPECTIVE

> All My Best Thoughts were stolen by the ancients.
> (Ralph Waldo Emerson)

Probably the earliest form of civilized use of solar energy dealt with man's home. "Solar tempered homes have existed since Neolithic times, when people crawled from their caves, rubbed the darkness from their eyes, and piled or pounded together their first structures." [Ref. 26]. Basically, any shelter, tent or other dwelling can capture sunlight in its skin and transfer some of the absorbed heat inside. This is known as a "passive" type of solar system -- see Chapter IV for a more detailed discussion of passive systems. At the same time it can shield the inside from some of the more undesirable side-effects of solar radiation. Such climate moderation is the normal effect of any shelter.

Shelters of more civilized peoples have taken advantage of the sun and were laid out on a grid system oriented to the direction of the sun; e.g., the entire Meso-American city of Teotihucan was laid out on a grid facing 15° west of south. Another example of sun orientation

is noted in the planning of Roman military camps which were always oriented within 30° of true south. [Ref. 26.

The sun was used as a source of military might over 2,000 years ago, too. The concept of burning glasses, that were used to light fires -- found in ancient ruins of Assyrian cities, some dating back to the 7th Century B.C. -- was claimed to have been used by Archimedes to set fire to Roman ships attacking Syracuse in 212 B.C., during the Second Punic War. According to legend, he lined up a thousand soldiers, each with a highly-polished shield, to reflect the rays of the sun on the sails of attacking ships. The sails burst into flames, and Syracuse was saved, at least temporarily. [Ref. 21].

Solar housing is ancient history right here in the U.S., where prehistoric Indian communities in New Mexico -- such as Chaco, Taos, Bandelier, and Gila Cliff Dwellings -- are some of the continent's earliest examples of sun-oriented housing. These pueblos were ingenuously engineered of earth and rock -- by people history remembers as master builders, potters and weavers -- to collect the sun's warmth in winter and shade it out in the summer. They worked so well, in fact, that many are still in use today. Further details and an illustration of these early examples of solar housing are found in Chapter VIII. [Ref. 43].

Many homes built in the U.S. in the early 1900s and up to the mid-1950s were also oriented to the direction of the sun. However,

with the advent of cheap natural gas and other energy sources to control the interior climate of buildings and residences, site orientation was no longer a critical consideration, and climate control relied on mechanical space heating and cooling systems.

Serious studies of the sun, its effects and potential, began in the 17th Century when Galileo and Lavoisier used the sun in their research and experiments. By 1700 diamonds had been melted using the sun's energy. In 1774, Joseph Priestly concentrated the sun's rays onto mecuric oxide and collected the resultant gas produced by the heating process. He had discovered oxygen. This finding enabled Lavoisier, the great French scientist, to propound the correct theory of combustion. At an exhibition in Paris in 1878, sunlight was focused on a steam boiler that in turn operated a small steam engine and ran a printing press. [Refs. 20, 44].

In 1901, in California, a large focusing solar collector in the form of a truncated cone developed 4-1/2 Hp using an area of 150 square-feet per horsepower. From 1902 to 1908, H. E. Willsie and John Boyle built four solar engines in St. Louis, Missouri, and Needles, California. By 1930, Dr. Robert Goddard, an early rocket specialist and scientist, had already applied for five patents on solar devices to be used on his project to send a rocket to the moon. [Refs. 20, 44].

In more recent history, solar water heating was a thriving business in the U.S. in the period between 1930 and 1950. In the 1930s

and 1940s, tens of thousands of these water-heating devices began appearing on rooftops of homes from Florida to California -- mainly the thermosyphon type described in Section G of this Chapter. As many as 8,000 of them may still be in operation. It is reported that there are 100,000 solar water heaters in operation in Israel and more than 1,000,000 in Japan. [Refs. 85, 86].

Similar devices were also used to heat commercial buildings. The first building in the U.S. to be practically heated with converted solar service-hot-water heaters was built at the Massachusetts Institute of Technology (MIT) in 1938. Some 20 other experimental building heating projects were completed over the 20-year period between 1938 and 1960. The U. S. Postal Service recently heated one of their postal facilities in Ridley Park, Pennsylvania, with solar energy. Performance data, recorded for a number of these projects, is still used in solar-heated building design today. [Ref. 38, 44].

However, it took the space age, and its billions of dollars in research and development, plus the need to power satellites in space using the sun's energy, to significantly advance the use of solar energy in the U.S. The current success of solar cells in powering NASA service modules and satellites in orbit, and in lunar excursions, led some engineers and scientists to propose other "earthly" uses of solar energy.

With the current "energy crisis" still facing us, the rapid escalation of fossil fuel prices sending utility bills out of sight, and the technological advancements made during the past 30 or more years in solar energy RD&D efforts, the time seems ripe for a rethinking the entire solar energy spectrum. While it can be said that solar energy is not yet "utopia" or the panacea to all our future energy problems, it does offer a sensible choice for the future.

B. SOLAR RADIATION CHARACTERISTICS

Most of the radiation striking the earth is called short-wave radiation and much of it is reradiated as longwave radiation after it strikes the earth. [Ref. 10]. It is this radiation that we are interested in, so far as application in solar energy systems is concerned.

Solar radiation (sometimes called solar insolation) is usually measured in Langleys per minute or Langleys per day. A Langley of radiation energy is equivalent to one calorie of heat per square centimeter. It is estimated that there are over 700 stations throughout the world that record radiation intensity continuously. These stations measure and report the solar radiation in terms of total Langleys received on a horizontal surface at ground level. A typical average solar radiation level for temperate regions is one Langley per minute for a surface tilted towards the sun on a clear day. This level of solar intensity can result in a total accumulation of 500 Langleys for a 500 minute day (approximately an eight hour day). Some useful

energy conversions are provided in Table III. [Ref. 19].

Table III. Common Solar Energy Intensity Conversion Factors

1 Langley/minute	=	1 cal/(cm^2. min)
	=	221 Btu/(ft^2. hr)
	=	3.688 Btu/ft^2
	=	0.700 kw/m^2
Assuming 500 min/day of solar radiation,		
1 Langley/min	=	500 Langleys/day
	=	500 cal/(cm^2. day)
	=	1841.7 Btu/(ft^2. day)

(Source: Ref. 19).

The importance of measuring solar radiation can not be underestimated in designing an effective solar system. The physical practicality and economic justification for purchasing a solar collector are closely related to the solar radiation measurements at a given location. [Ref. 20]. The annual monthly solar radiation intensity characteristics for specific geographical regions can be found in numerous sources available for that purpose.* Appendix D contains a sample listing

*For information on solar radiation intensity levels, refer to one of the following: Bennett, I., "Monthly Maps of Mean Daily Insolation for the United States," Solar Energy, v. IX, no. 3, 1965; Environmental Science Services Administration, Climatic Atlas of the United States, Washington, Department of Commerce, 1968; Dawson, J., Buying Solar, Federal Energy Administration, Department of HEW, June 1976.

of average monthly solar radiation intensities received at several locations.

C. AVAILABILITY OF SOLAR RADIATION

The sun is in essence a colossal thermonuclear generator that continuously bathes the earth with pollution-free radiant energy. Accompanying harmful radioactive particles are mostly trapped in the earth's upper atmosphere. [Ref. 21].

The amount of the sun's energy intercepted by earth is only a tiny fraction -- one thousandth of one millionth -- of the total released by the conversion of 4 million tons of hydrogen per second to helium in the sun. A major portion is lost in space due to reflection, absorption, diffusion, etc. However, it is said that in only 15 minutes the earth intercepts as much radiant energy from the sun as man consumes each year in the form of fossil fuels and nuclear energy; and in less than 4 days accumulates an amount equivalent to all of the earth's fossil fuels that have built up over the millions of years they took to form on this planet. If consumed at the present exponential rate, estimates are that these fossil fuels will be completely used up in a few more hundred years, at most. [Refs. 14, 21]. However, the sun's energy has been radiating energy for 500 million years and will continue to radiate down on the earth for at least another 50 million years. [Ref. 23].

Lake Erie alone is bombarded with enough solar radiation to supply the total U.S. demand year round. Equivalently, enough solar radiation falls on the roof of the average U.S. house to satisfy all of its annual needs. For example, each square meter (10.4 square feet) is bathed in about 1,000 watts of solar radiation -- enough to power ten 100-watt lightbulbs continuously. [Ref. 22].

D. ADVANTAGES OF SOLAR ENERGY

Some of the more pertinent advantages of solar energy, as an alternative to dwindling sources of fossil fuels, are listed and briefly discussed below:

1. <u>Continuously Renewable Source.</u>

Due to its origin from the sun, solar radiation (insolation) is virtually inexhaustible and with almost unlimited availability. It requires no depletion allowance to encourage exploration; it cannot be embargoed by a cartel of a few producing nations.

2. <u>Alternative to Nuclear Power.</u>

The direct conversion of solar radiation to useful energy is perhaps one of the few significant long-range alternatives to nuclear power, which has been curtailed during the past few years due to strict safety and environmental controls levied at both the State and Federal government levels.

3. Relatively Low Cost

Solar energy, itself, is free, except for the initial capital cost of capture and conversion to a usable form. However, this initial capital cost is one of the fundamental reasons why solar energy is not cost competitive on a broad scale with fossil fuel-fired systems in many parts of the country. Installation costs will be discussed in more detail in latter Chapters of the thesis. However, the major cost advantage now is that once a solar energy system is installed, the sun's energy from that point on is "free" and has virtually no inflationary effect, except perhaps, that associated with maintenance and repair costs.

4. Cost-Effective Source.

Fossil fuels are extremely costly now and will continue to escalate in price as supplies diminish. This means solar energy systems are cost-effective in many situations now, and should continue to improve in the years ahead. Solar energy equipment installed today has a life expectancy of between 20 to 25 years. An additional advantage often overlooked is that maintenance costs are very small compared to those of most fossil fuel generating systems. [Ref. 24].

5. State-of-the-Art Technology.

Solar energy has been used by man for over 2,000 years of recorded history. The technology exists today for space heating and cooling, water heating, photovoltaic uses, etc. Yes, there is a need

for improved technology for cooling and there could be some improvements in heating applications, but, the technological problems are minor and can be overcome. The technology for solar energy use for space heating and water heating is available today.

6. Environmentally Attractive.

Solar energy is quiet, clean, and non-polluting. In addition, solar energy requires neither transmission of fuel, large central distribution or generating plants, nor distribution lines, etc. It can be produced in small electrical converters -- solar cells or collectors -- wherever the energy is to be used. Unlike oil, solar energy does not blacken our beaches or rivers, nor darken our skys, nor pollute the air we breath or water we drink. Unlike coal, solar energy does not ravage our rural landscapes with strip-mining or our more urban atmospheres with sulfurous fumes, nor does it cause the dreaded "black lung." Unlike wood, solar energy cannot be fired by lightning strikes in drought-stricken forests or by carelessly tossed matches, causing thousands of acres of valuable timber and watershed to burn up, further blackening our air and land areas, and destroying wildlife and sometimes human life.

7. Energy Self-Sufficiency.

Because of the universal nature of solar energy -- available to all peoples of all countries, without regard to physical, political or human boundaries -- its generation is not centralized or limited

to specific locations, and hence it is not subject to sabotage or political blackmail. The political ramifications of our Nation's policy to seek a degree of energy self-sufficiency are fairly well summed up in the following passage:

> ".... We have reached the point where we can hardly live with the political distribution of fossil fuels and, a little later on, uranium deposits. Solar energy may be a political necessity. All the far-flung plants in the sun belt could be built by an international consortium of producers and users. After all, the resource is so widely spread that it is cheaper to try to collect it than to fight for it. There can be no absolute monopoly at all levels. The man who does not want to heat his house by buying hydrogen made on the coastal deserts of South America (or the oil from the Middle East) can always say to hell with it and run up a collector on his roof. He will learn a lesson in self-reliance and he will teach it to his neighbor .... Liberty can come from independence just as it has come from abundance.
> (Daniel Behrman) [Ref. 25].

8. <u>Abundant Supply</u>.

> The enormous magnitude of the solar radiation that reaches the land surfaces of the earth is so much greater than any foreseeable needs that it represents an inviting technical target ... If only a few percent of the land area in the U.S. could be used to absorb solar radiation effectively (at say a little better than 10 percent efficiency), we would meet most of our energy needs in the year 2,000. Even a partial achievement of this goal could make a tremendous contribution.
> (Chancey Starr) [Ref. 9].

E. DISADVANTAGES OF SOLAR ENERGY

Unfortunately, solar energy cannot be considered the panacea for the Nation's energy problems. In fact, there are many major disadvantages -- or drawbacks -- to the use of solar energy systems.

These drawbacks can be categorized into four basic categories: technical, economic, institutional and others. These categories are described briefly below:

1. Technical Barriers.

The diffuse nature of solar -- that is its characteristic of being spread out widely and thinly -- is its major barrier. The sun's rays are spread diffusely over the surface of the earth and are intermittent; the sun shines only during the day and is frequently obscured by clouds. To harness large amounts of solar energy, collectors must be spread over a large area, and the larger the area the higher the cost. A second technical barrier is storage. With most solar techniques, only a portion of the energy is used immediately; the rest must be stored for future use when demanded by the user. The cost of storage is usually a significant portion of the entire system cost. However, this situation can be remedied by the use of a conventional back-up heater, as previously mentioned.

2. Economic Barriers.

The economic barriers to utilization of solar energy systems primarily result from the fact that high initial costs are required for solar systems, even though operating costs are relatively low. Costs will be the subject of a more in-depth review in latter chapters and appendices of this thesis.

3. Institutional Barriers.

The institutional barriers are more psychological than technological in nature. People and institutions, and even the Government, do not usually give serious consideration to lifetime energy costs, e.g., life-cycle costs, when they construct a facility or residence. Because of the historic low costs of fossil fuels, there has been no real economic incentive in the past to establish industries that manufacture, install, guarantee, and maintain solar energy equipment and systems. However, with the rapid escalation of fossil fuel costs and the depletion of these fuels, various Government and institutional incentives such as guaranteed loans, outright grants, and increased RD&D efforts regarding use of solar energy systems should make the solar industry a viable one in the future.

4. Other Barriers.

There are other barriers that inhibit the widespread development and use of solar energy, but these too are more psychological than technological; e.g., objection to roof-top solar collectors from an aesthetic viewpoint and the reluctance to use new technology.

One author in the field of solar energy has this to say about the disadvantages of solar energy today, which pretty well sums up its disadvantages:

> ... Solar energy has the drawback of being diffuse. Rather than being mined or drilled at a few scattered places, it falls thinly and fairly evenly across the globe.

> ... Governments and industries accustomed to concentrated energy supplies are ill-equipped by reason of economic constraints or philosophical prejudices, to harness this gentle source of energy. These institutions are far more interested in forms of energy that lend themselves to centralization and control. Hence, the United States government spends billions for nuclear power while solar energy is just a subject for study -- a future possibility, maybe, but not for now. (Bruce Anderson) [Ref. 26].

5. Solar Energy: A Cop Out?

One can certainly argue the advantages and disadvantages of solar energy and argue successfully for either view. And probably, in the short run, its economic disadvantages may slightly outweigh its advantages in the decision-making process. In the view of many experts, solar energy is not *the* answer to our energy problems. Professor Otto Eckstein, of Harvard University and President of Data Resources, Inc., has stated: "Solar ... is a cop out ... all too many people take on energy policy ..." He further indicates that "... when someone talks about solar as ... the answer to energy, you know he is dodging the issue." [Ref. 101]. In reply to a personal query to Professor Eckstein about his meaning that solar is a "cop out" he replied:

> The quote ... came out a bit stark, but its meaning is correct, I believe. In the political context, a focus on solar energy really means that the person involved is not willing to deal with the near-term problems which pose some really tough choices. To be for solar energy, and to pour a few more hundred million dollars into some kind of research in that direction, is a pretty non-controversial business. But how to get the American people to conserve energy use and to get them to be willing to pay the full market value of energy, these are the tougher matters to deal with.

> There is the question of the time schedule of the energy crisis. Solar energy may make a small but significant contribution to total energy supplies by 1990, and it is a good idea to get started on this technology. But ... the energy crisis is upon us now, and the question is how we get through the next 14 years first. (Otto Eckstein) [Ref. 102].

A facsimile copy of Professor Eckstein's personal letter is contained as Exhibit II.

F. SOLAR SYSTEM COMPONENTS AND OPERATION

1. Components

a. Solar Collector Panels

These are normally flat plate fluid-based collectors, that either sit on the roof or separately away from the building on a ground array. A closed system will employ copper tubing with a heat transfer fluid -- some type of anti-freeze solution. An open system circulates water over the absorber plate and drains when not in use to prevent freezing. From 20 - 80 square feet of collector is required for a typical water heating system; much more is required for a space heating and cooling system. Collector size can be computed using various available source material as a guide. (See Appendix B and C).

b. Solar Storage Tank

This is basically a conventional water heater without the heating coil element, although specific solar tanks are manufactured for this purpose. A closed system will employ a heat exchanger coil

in the tank to heat the water. An open system merely circulates the water in the tank through the collector.

c. Associated Plumbing Fixtures.

Pumps, valves and sensors are necessary to activate the system, circulate the fluid, and safeguard overheating or high pressure.

2. Operation

The system operates as follows in a closed system:

a. Cold water flows into the solar storage tank.

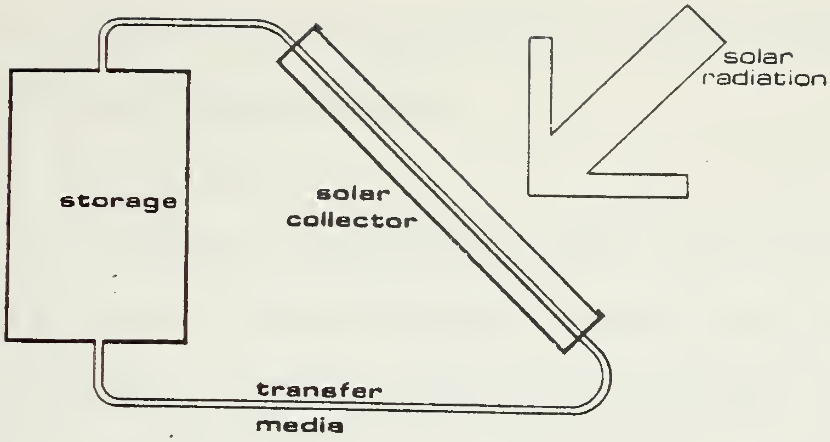
b. The sensors activate the pump which circulates the heat transfer fluid.

c. The heat transfer fluid absorbs heat as it passes through the collector.

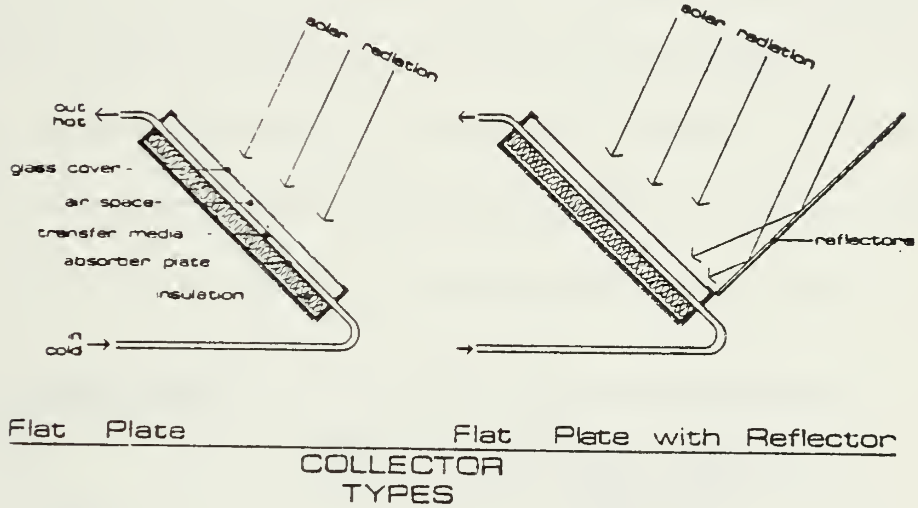
d. The fluid transfers heat to the water as it passes through the heat exchanger coil.

e. The heated water flows into the conventional water heater tank for storage until demanded from the house taps or space heating system.

See Figure 4 for an illustration of basic components of solar energy systems, and the various types of collectors that can be used with the system.



Basics of solar energy systems



Above and below: collector types

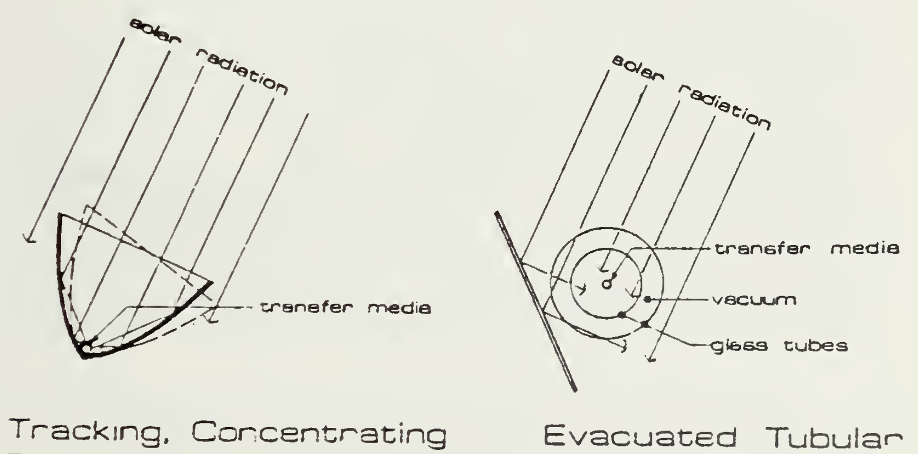


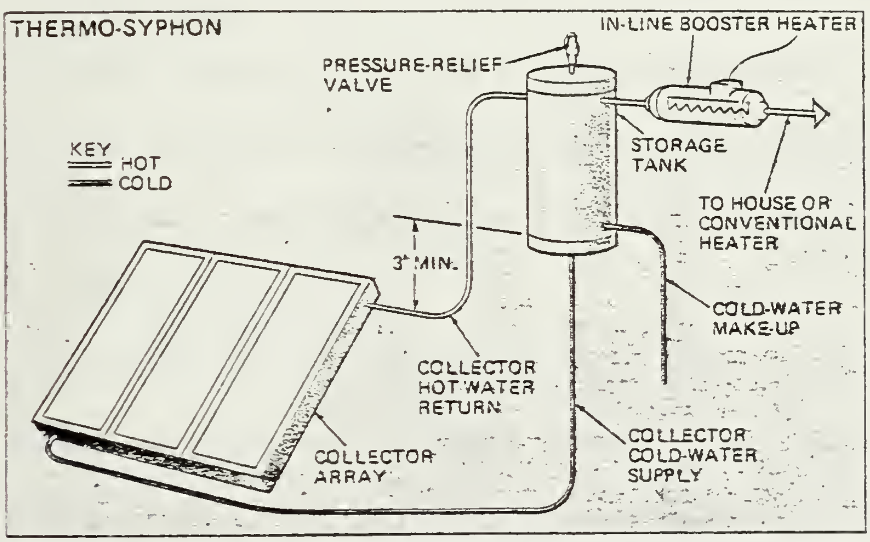
Fig. 4. Collector Types and Basics of Solar Energy Systems
(Source: unknown)

G. SOLAR SYSTEM TYPES AND OPERATING CHARACTERISTICS

1. Heating and Cooling Systems

a. Thermosyphon

The simplest form of solar system is the thermosyphon concept. It operates on the principle that in a water tank cold water will sink and thereby displace hot water causing it to rise. The water heated in the solar collector will flow up into the storage tank because warm water rises, just as warm air rises. The bottom of the storage tank must be at least two feet above the top of the collector for proper operation. This will prevent circulation from flowing in the wrong direction. The thermosyphon system eliminates the need for pumps and controls. Figure 5 illustrates the thermosyphon concept.



Essentially passive system relies on gravity and convection to circulate water: Cold water flows from bottom of tank to bottom of collector, returns when warmed.

Fig. 5. Typical Thermosyphon System (Source: Ref. 42).

b. Liquid Heat Exchanger

Instead of using water, which freezes, an anti-freeze solution can be used in the solar system to make it surrender its heat to the water through a heat exchanger, usually a coil of tubing inside -- or around -- the storage tank. Building codes require a double-wall heat exchanger due to the poisonous nature of the anti-freeze and to keep it separate from the potable water system. The anti-freeze solution must be changed periodically, just like anti-freeze in the radiator of your car. Figure 6A illustrates the components of the liquid heat exchanger system.

c. Draindown

The draindown system allows for a more remote tank location. A pump moves water through the collectors only when there is enough sunlight to prevent freezing and to produce heat. At other times, the pump is shut off and the solar collectors are drained. Figure 6B illustrates the components of the draindown system.

d. Air Heat Exchanger

The air heat exchanger idea uses air in lieu of antifreeze solution. Water from the system's tank is pumped to a heat exchanger, where it is heated by air circulated from the solar collector, and then returns back to the tank. The heat exchanger is less efficient than heating water directly, but it helps eliminate the freezing problem. Figure 6C illustrates the components of the air heat exchanger.

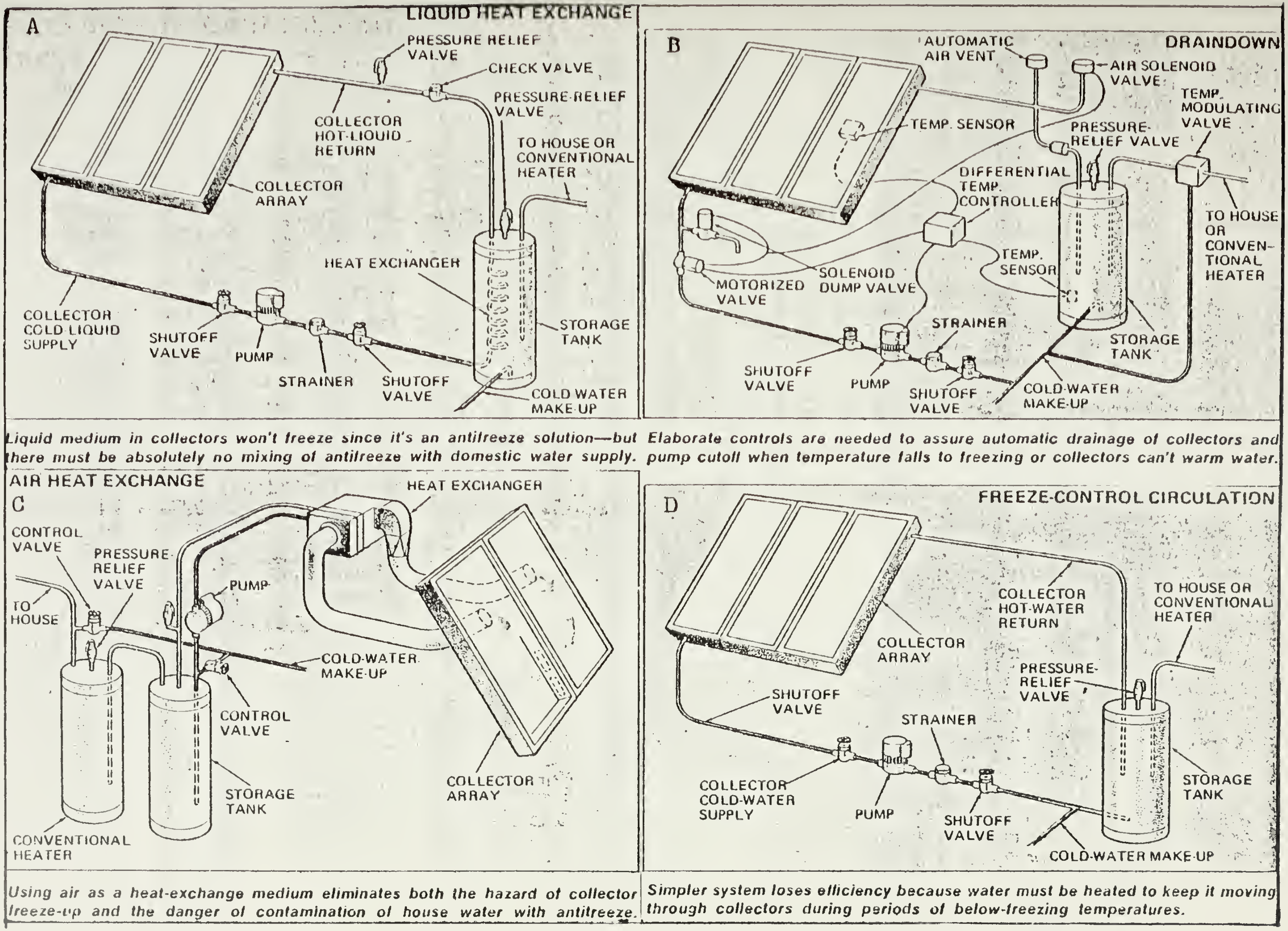


Fig. 6. Typical Solar Energy Systems
(Source: Ref. 42).

e. Freeze-Control Circulation

Freeze-control circulation allows for a remote tank location. This less-commonly used system uses "freeze-control" circulation from the storage tank. Warm water is kept moving in the solar collectors when the temperature drops below freezing. It is somewhat less efficient than the draindown system because it uses heat to warm the collectors, but it has the advantage of using simpler controls. Figure 6D illustrates the components of the freeze-control circulation system.

The descriptions and figures used in this section have been taken from "How to Get Hot Water from the Sun Right Now," Popular Mechanics, v. 148, p. 131-137, September 1977. [Ref. 42]. Additional information on solar equipment and how to shop for it can be found in Buying Solar, a publication of the Federal Energy Administration, Stock No. 041-018-00120-4, June 1976, which is available from the Superintendent of Documents, U. S. Government Printing Office, Washington, D.C. 20402 (Cost $1.85).

2. Experimental Solar Energy Systems

a. Photovoltaic (Solar Cell) Systems

A photovoltaic cell is a device which converts sunlight directly into electrical energy. The modern cell -- sometimes referred to as a solar cell -- was just invented in 1954 and many of the cells

built in the 1950s continue to operate to this day. A typical silicone photovoltaic cell is shown in Figure 7. The single crystalling silicone solar cell is an efficient longlife photovoltaic device. This cell is used exclusively in the space program and it is used in nearly all of the commercially available small terrestrial systems. The first satellite to use solar cells was Vanguard I, which went into orbit on 17 March 1958. This small satellite carried a 5-Mw transmitter powered by six solar batteries. For about six years it sent back signals giving valuable information and showing the feasibility of direct use of solar energy for communications in space. Many other satellites followed, including Telstar and the fixed-position satellites which give worldwide communication channels. NASA Johnson Space Center in Houston, Texas, is currently looking into additional ways that outer space might supply energy. NASA is currently developing a shuttle-launched satellite that will collect solar energy in space and beam it back to earth. Also, in late 1983, the shuttle will put into orbit a $450-million, solar-powered telescope, which, freed from the interference of the earth's atmosphere, will enable scientists to gaze seven-times deeper into space than ever before. [Refs. 19, 52, 94].

Photovoltaic cells hold exceptional promise for the future in large-scale power generation if the costs can be reduced. The cost challenge of photovoltaic cells is illustrated by the solar cell array on the Skylab space station orbited by the U.S. in 1973 and occupied by

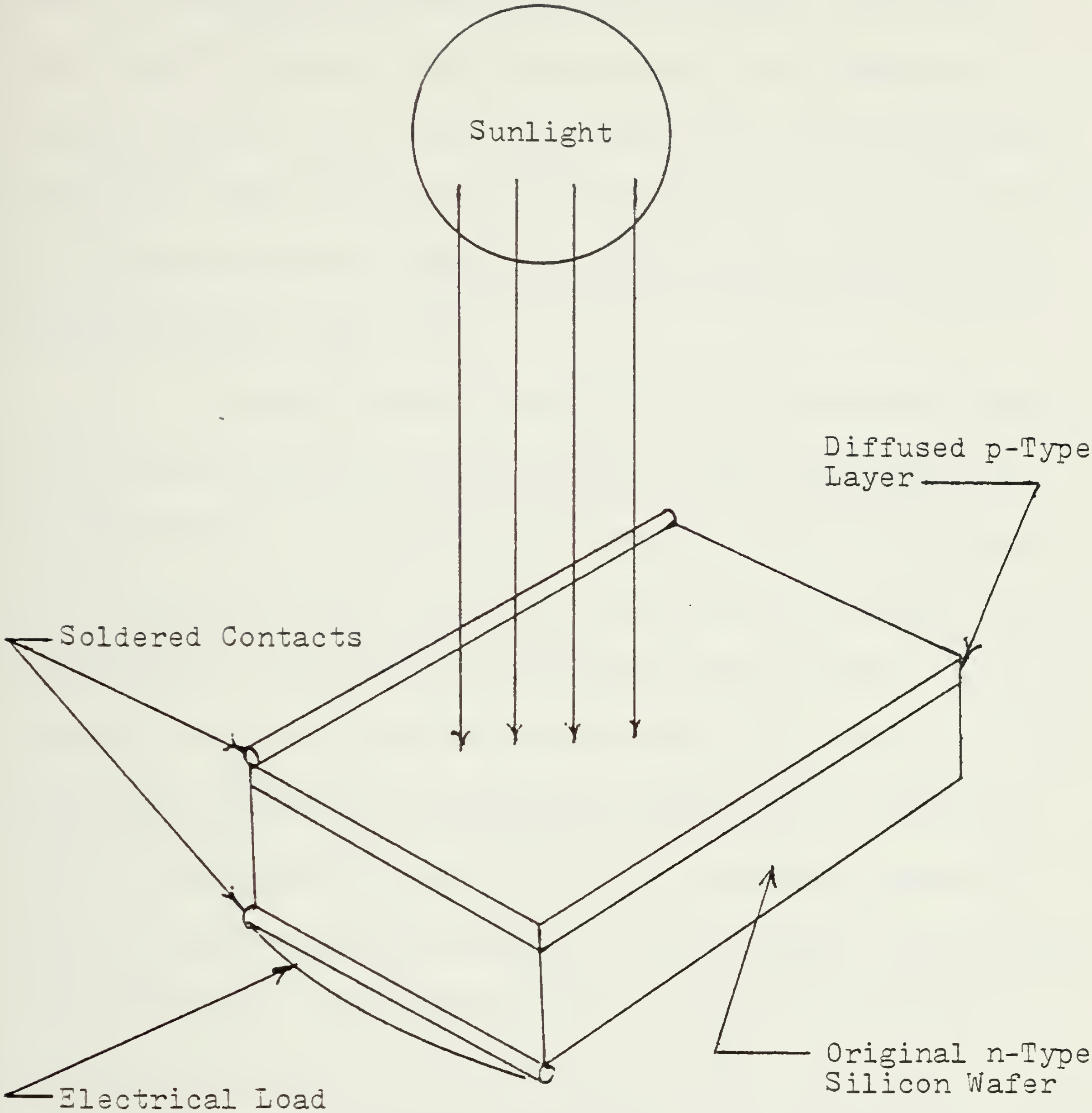


Fig. 7. Typical Silicon Photovoltaic (Solar) Cell
(Source: Ref. 19).

teams of astronauts for periods ranging up to 84 days. The array was designed to produce 10 kilowatts and cost about $2 million per kilowatt to build. This is about 4,000 times the cost of power generation capacity using coal-fired or nuclear-powered plants. The goal of the current photovoltaic program is to drive the costs down to around $500 per kilowatt. [Ref. 11].

Present research funds of the Solar Photovoltaic Conversion Program go primarily towards study of silicon solar cells and associated devices. Research, development and demonstration efforts on novel material and devices, such as heterostructure single crystals and thin films of silicon and cadnium sulfide/copper sulfide, are proceeding, but at a relatively low level of funding. Thin film silicon photovoltaic cells seek to accomplish two objectives: (1) reduce the cost of manufacturing the silicon cell and (2) significantly reduce the amount of high grade silicon necessary to make the cell. Unfortunately, recent efficiencies of only 4% have been reported and projections are that only 10% efficiencies can be achieved by 1980. [Ref. 18].

Another promising photovoltaic cell is the gallium arsenide (GaAs) cell. Although the individual cells are not presently economical, systems using them might be very low in cost because they can be used with concentrators. In areas of the Southwest U.S. where large amounts of direct sunlight are available, the Concentrator/GaSa cell system seems promising for large-scale applications.

Scientists in the research division of International Business Machines Corporation (IBM) are claiming a major increase in the overall efficiency of the GaSa cell, from 11% just six years ago to about 22% today. This cell arrangement is coated with a thin layer of gallium aluminum arsenide and comes close, IBM claims, to the theoretical maximum efficiency of GaSa cells, which is 27%. By comparison, the best silicon made cells have an efficiency of only 18%. [Refs. 18, 48].

The Department of Defense recognizes the potential of photovoltaic systems and as such is considering its future development in a 21-year plan, called the Photovoltaic Power System (PPS) Plan. Its purpose would be to develop and then install such systems at promising Federal and Navy sites. Two factors make the plan attractive for military application: (1) its simplicity and (2) the ability to combine solar cell modules to create either small systems with a capacity of several watts or a central power facility with the capacity of generating many megawatts power. [Ref. 46].

Realizing the importance of future solar cell applications in the Department of Defense remote and isolated sites, the Navy has prepared an encompassing Photovoltaic (Solar Cell) Power Systems Plan. The Navy's Civil Engineering Laboratory (CEL), as lead activity for all shore facilities energy R&D, is providing support to the Naval Facilities Engineering Command (NAVFAC) in this endeavor. Accordingly, the CEL has prepared a bibliography of photovoltaic documentation, providing all current literature on solar cells. [Ref. 95]

This Fiscal Year 1978, in cooperation with the Department of Energy (DOE), the CEL will manage a program calling for the installation of photovoltaic power systems at several selected sites. One tentative location is the Naval laboratory test facility in Bermuda where a medium size array of solar cells will be installed. Another scheduled site is a remote mountain top at a West Coast Naval installation where a hybrid wind/solar cell will be operated. A CEL-sponsored report is available on the "Study of Solar Augmentation of Electrical Power at Pacific Missile Test Center Remote Island Sites," Technical Memorandum 76-15. The study describes the power requirements of various Naval installations on San Nicolas Island and the availability of solar radiation to power solar cells. Supplementary analyses indicate that solar cells are an encouraging substitute for diesel/electric power at remote areas. [Ref. 95].

Considerable interest in solar cells has been generated by a recent Department of Energy study of Federal government utilization of the photovoltaic concept. The study indicated that if the Federal government were to install 152 megawatts-electric (MWe) of photovoltaic cells at remote or isolated sites, the direct net benefits would be far greater than had been previously expected. Perhaps even more importantly, such a purchase would go far in stimulating a viable photovoltaic industry, potentially resulting in lower prices, which would, in turn, create a larger and growing market in the

private sector. The study further claims that an investment of less than $500 million (in 1975 dollars) for the 152 MWe system would return $2 billion gross over the lifetime of the systems -- estimated at 20 years -- plus their period of installation, staggered over five years. Using the standard Federal government discount rate of 10% during this period, the benefit would be $500 million in net discounted present value. (See Appendix B for further discussion on the 10% discount rate required by the Federal government and a brief explanation of discounted present value analysis). The study continues with an assumption that the devices would be replacing 20% of the diesel generators within DOD and that escalation of fuel, operation and maintenance costs would be zero, equal only to general inflation. (Appendix E also contains information on the general fuel inflation rates used by the Federal government). [Ref. 95].

Other applications of photovoltaic systems in use around the world and in the U.S. include the following:

(1) Operational navigational aid system administered by the U.S. Coast Guard in Miami Bay. The project consists of 50 aids -- 30 fixed and 20 buoy -- which are being converted to solar photovoltaic power supply to demonstrate the long-term reliability of photovoltaic devices on operational navigation aids. [Ref. 47].

(2) Horns on unmanned off-shore platforms.

(3) Maritime buoys.

(4) Educational television receivers (in Africa).

(5) Radio repeater stations.

(6) Environmental monitoring equipment.

(7) Battery chargers for small boats.

(8) Light measurement instruments.

(9) Transistor field radios powered by solar batteries.

(10) Railroad warning and signaling systems.

(11) Remote telephone system power.

(12) Transistor field radios powered by solar batteries used by the U. S. Army. [Refs. 19, 52].

b. Microwave Power Transmission from Space

> Before long, we may be building castles in the air. They won't have turrets or moats, but these castles will seem just as dreamlike. They will be outposts in space, perhaps factories where men manufacture medicine or industrial products, or power stations beaming energy back to earth ... Since no technological breakthroughs are needed to make space stations a reality, the greatest barrier may be psychological.
> (Brian Sullivan) [Ref. 50].

These words project an image that solar energy systems in space, while no longer a Rube Goldberg concept, are not quite a Buck Rogers concept either. Space vehicles powered in space by solar cells (see the previous section on Photovoltaic Systems) dispelled this concept. In quoting the Boeing Aerospace Company, which is involved in the space programs for the Nation, the fact is that "... hardnosed engineering studies show that, while challenging, all this is technologically achievable within a relatively short time." [Ref. 50].

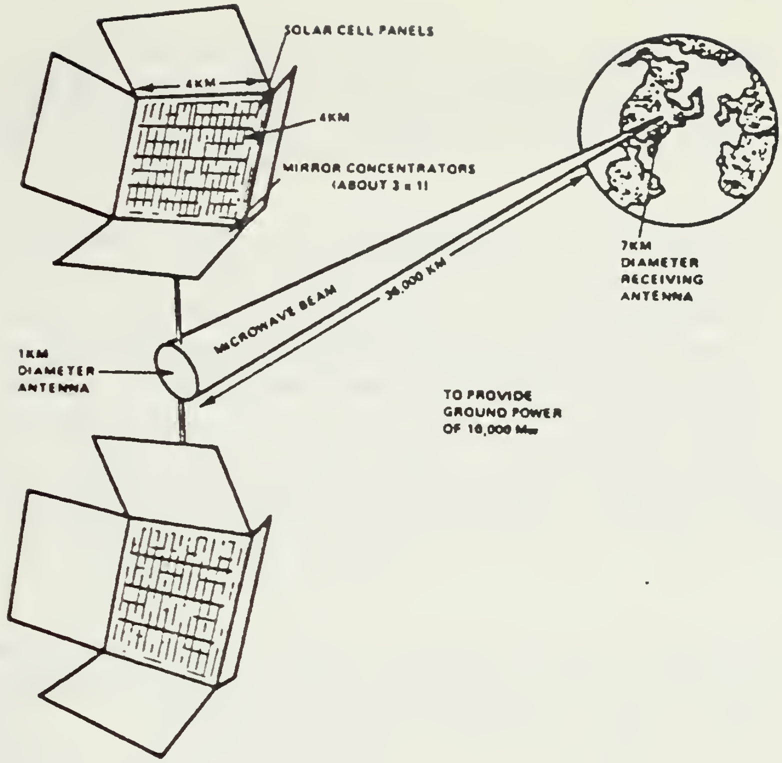
Another concept, equally challenging, is to locate a solar power station capable of receiving almost pure solar radiation in space. The station would serve as a gigantic power station consisting of a large number of solar cell modules, in stationary synchronous orbit around the earth's equator. Figure 8 illustrates what the typical space satellite system with concentrators might look like in the future and Figure 9 illustrates the space satellite power system efficiency estimate where the station would receive almost pure solar radiation. [Ref. 19].

These space stations won't be small either.

> A 10,000 megawatt power station -- enough to meet all of New York City's needs in the year 2,000 -- would encompass about 25 square miles of area and weigh five-million pounds. The receiving antenna would be nine square miles.
> (S. David Freeman) [Ref. 45].

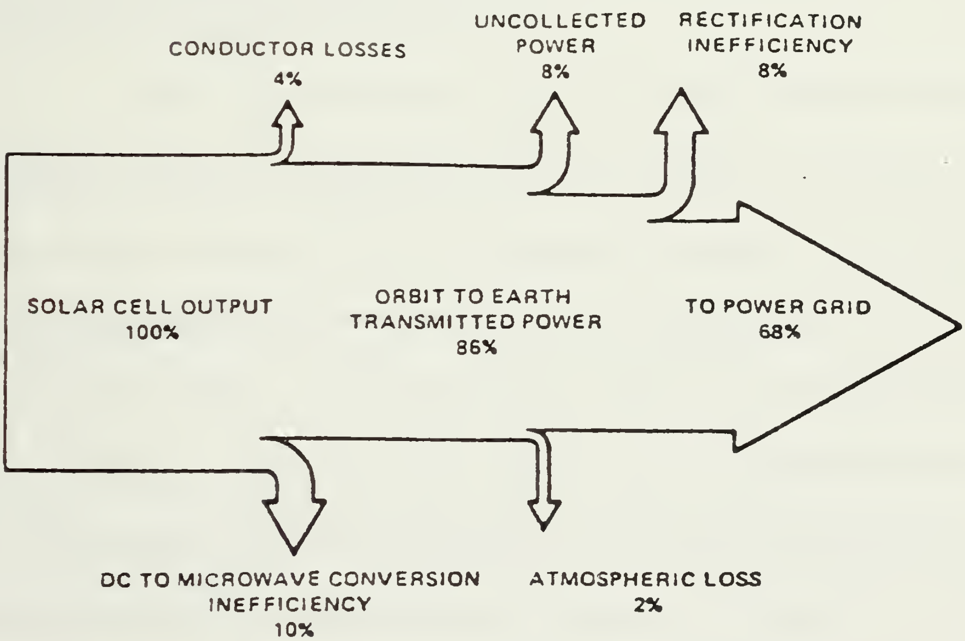
In regards to the diffuse nature of solar radiation on the earth's surface, further discussion in support of the space platform concept is offered as follows:

> One reason is that the power should be "above the clouds" and could be a steady source of electricity 24 hours a day, 7 days a week. Another is the intensity of the sun's rays, the so-called solar flux, is seven times as great in space as the average on earth because the atmosphere surrounding this planet absorbs and reflects much of the solar energy. Thus the same solar cells can produce more electricity in space than on earth, and can do so around the clock.
>
> The power plant in space would also virtually eliminate the waste heat or thermal pollution inherent in all types of central station power plants on earth, which



Source: Martin Wolf, Hearings before the Subcommittee on Energy of the Committee on Science and Astronautics, U.S. House of Representatives, June 6 and 11, 1974.

Fig. 8. Space Satellite Power System with Concentrators (Source: Ref. 19).



Source: Peter E. Glaser, "Space Satellite Power System," Solar Energy Lecture III, IEEE Washington, March 28, 1974.

Fig. 9. Space Satellite Power System Efficiency Estimate (Source: Ref. 19).

waste over half the energy they consume. The microwaves could be beamed to earth and converted to electricity with efficiencies of approximately 90%, thus minimizing the waste heat problem.

All of these features make the solar power plant in space an attractive concept. But is it really practical or just 'pie-in-the-sky'? No one can be sure but the concept certainly presents fewer technical obstacles than did going to the moon when the space program was launched by President Kennedy. In fact all of the basic technology for the solar power plant, microwave transmission and receiving station are in hand. And the space shuttle ... could provide the earth-to-orbit transportation system that would be necessary.

What is required to make the solar power plant concept technically feasible is an immense systems engineering effort. .... But technical feasibility is within the range of possibility and would appear to involve fewer uncertainties at the moment than the development of fusion power, for example.

The question of costs -- the economics of solar power in space -- looms as a major hurdle.
(S. David Freeman [Ref. 45].

Such ideas seem like science fiction, but the Federal government, through agencies like ERDA and NASA, and large corporations in private industry are serious about the ideas. A Boeing Aerospace Company concept shows a solar power satellite as a four-segment array stretching 14.7 miles across space, collecting energy and beaming it back to earth as usable electricity. The NASA Marshall Space Flight Center recently awarded a $110,000 plus contract to General Dynamics to study the space formation of beams -- a concept to become part of NASA's industrialization of space. Grumman

Aerospace Corporation is building a ground demonstration module for beam fabrication under contract with NASA-MSFC. Rockwell International is also studying a solar power space satellite for NASA. [Ref. 50].

NASA has recently made grants to support RD&D of two new concepts that are even more mind-boggling than those above.

> One of them is . . . (an idea for a) . . . . "mass-driver," a new way to propel matter. It is a series of catapults that would be built on the moon, and filled there with lunar surface material. The catapults would hurl this stuff toward a more specific spot in space where it would be caught. There the abundance of minerals in the lunar soil would be extracted chemically and used to construct solar power stations or a space habitat. The second grant is for a study of such chemistry. A demonstration model of a mass-driver has been built at the Massachusetts Institute of Technology. (Brian Sullivan) [Ref. 50].

H. SOLAR ENERGY EQUIPMENT CATALOGUE REFERENCES

Several sources of information exist that provide descriptions of solar collectors as well as other items of solar equipment available. Three of these sources are: (1) <u>A Catalog on Solar Energy Heating and Cooling Products</u> -- a 400 plus page volume which describes most of the available solar equipment; (2) <u>Solar Heating and Cooling Demonstration Program, A Descriptive Summary of HUD Cycle 2 Solar Residential Projects</u> -- a 103 page publication 102 different solar energy projects sponsored by HUD designed to provide the public with a general look at various selected projects including the location and

size of the project, a drawing of the unit, and describes the energy system used -- a sampling of the information is included in Appendix F; and (3) Solar Heating of Buildings & Domestic Hot Water by the Navy's Civil Engineering Laboratory which provides information on design options and a directory of manufacturers of solar energy equipment. [Refs. 70, 71, 36].

One commercial firm, Horizon Industries, has recently published a solar water heater design manual which may be able to help in this particular area. This new manual is claimed to detail techniques developed by a practicing solar engineering group. Called "A Design Manual for Solar Water Heaters," it presents a complete, step-by-step design procedure leading to selection of the type, size, and orientation of the collector; the type and size of the storage tank; the type and size of the pumps; the specifics of the control system; and the anticipated fuel/dollar saving. Also included are methods for computing and optimizing the rate of return for both constant and increasing fuel rates. The 40-page guide is available for $5.00 from Horizon Industries, 12606 Burton Street, North Hollywood, California 91605.

Another manual, called "A Guide to System Sizing and Economics of Solar Water Heating in Florida Residences," published by the Florida Solar Energy Center, 300 State Road 401, Cape Canaveral, Florida, 32920, is also recommended. The manual has been prepared to answer questions like: "How big does a solar water heater have to be for my

needs?" and, "What do the economics look like?" It provides a series of graphs which enable the user to size a system according to needs and to determine the economics of the investment. The manual also contains worked out examples for the reader as well as system descriptions, buying tips and a bibliography. The manual is designed primarily to serve an audience of non-technical but interested and motivated laymen and to be a useful document for engineers, architects, manufacturers and marketers of solar equipment. [Ref. 76].

I. METHODS OF ECONOMIC EVALUATION

The widespread use of solar heating and cooling systems in buildings, both commercial/industrial and residential, hinges in large part on their economic performance in relation to conventional fossil-fuel heating and cooling systems. In deciding the economic advantages of one energy system over another one, the decision maker should be aware of the "total costs," not just the initial capital costs, but the follow-on operating and maintenance costs as well. Too often in the past, investment decisions have been made on the basis of the initial first-costs alone -- or made without taking into account all the indirect associated costs as well. To make these decisions, reliable and consistent procedures are needed for the collection and analysis of economic costs and benefits associated with the various systems being evaluated.

Embodied in this "total cost" concept are two methods felt by the author to offer the best approachs to the economic analysis of new solar energy programs/projects/systems: (1) life-cycle cost analysis and (2) benefit-cost analysis. A full and detailed discussion of these two analysis approaches is beyond the scope and intent of the thesis, which is intended primarily as a resource document for researchers and persons interested in the many aspects of solar energy systems in general. For the purposes of further discussion in this Section, only a brief description of these two methods will be given for a basic understanding of their approach to economic analysis. Additional information on this subject is provided in Appendix B which primarily concentrates on economic evaluation of solar systems from the standpoint of life-cycle costing.

1. Life-Cycle Cost Analysis

Life-cycle cost analysis provides a measure of the total costs of owning and operating a system over the life of the system rather than focusing solely on the initial capital cost of the system. Almost invariably, the initial costs of the solar systems will be higher than conventional fossil fuel systems. However, in many cases, the annual savings accrued through use of the solar systems will pay back the increased initial cost. Life-cycle costing, rather than initial-investment costing, is the appropriate way to determine the cost-benefit ratio for a solar system because initial-investment costing does not

take into account the cost of fuel saved during the life of the solar system. For further detailed information on this approach refer to Solar Heating and Cooling in Buildings: Methods of Economic Evaluation, NBSIR 75-712, by Rosalie T. Ruegg, National Bureau of Standards, Final Report, July 1976, or to Appendix B.

2. Benefit-Cost Analysis

In benefit-cost analysis the general principles are that (1) a program should not be undertaken or adopted unless its benefits exceed its costs, and (2) as between competing alternative energy proposals the one with the greater excess of benefits over costs, or the one with lower costs if benefits are equal, is preferable. Benefit-cost analysis focuses on those consequences of an alternative energy proposal which can be estimated in quantitative terms. But, since there is no important energy problem in which all relevant factors can be reduced to numbers, benefit-cost analysis will not provide the complete answer to any important energy problem. However, as its primary purpose is to suggest to the manager or decision maker the best alternative way of reaching a decision in selecting a specific alternative energy proposal, benefit-cost analysis can provide management with a valuable tool for comparing various energy systems in terms of benefits and costs. Other terms often associated with benefit-cost analysis are cost-effectiveness* and systems analysis. For further information

*If two programs have approximately the same benefits, but one has fewer costs, that one is said to be more cost effective than the other.

on benefit-cost analysis refer to Appendix B.

3. Disadvantages to Methods of Economic Analysis

A primary characteristic of many new, experimental, promising solar energy or alternative energy programs/projects is that there is no way of estimating the total life-cycle costs or benefit-cost relationships in advance. Therefore, undue insistence on life-cycle costing or benefit-cost analysis can result in an overly conservative program/project approach. Although the risk of failure of an innovative energy proposal may be high, it may be a risk worth taking, especially in view of the fact that we are running out of fossil fuel sources and may have no other alternatives in the future. Recognize the fact then that there are some disadvantages in using these two methods of analysis.

On the other hand, there are some fallacies that the decision maker must contend with that are often urged in support of alternative energy system proposals when either the life-cycle or benefit-cost analysis process is not used. These fallacies are:

a. An alternative energy project is important; therefore more money should be spent on it.

b. It should be done because others do it.

c. It should be done because it has always been done.

d. It should be done because an outstanding authority recommends it; or, it should not be done because an outstanding authority recommends against it.

4. Life-Cycle Computer Simulation Programs

There are several computer simulation programs that have been developed to assist the decision makers and managers exercise the life-cycle analysis model. Several of these models -- BASIC Language, F-Chart Calculation, and SOLCOST Calculation -- are discussed briefly in Appendix C.

5. Solar Space Heating and Water Heating Analysis Results

The analysis and results of several recently completed solar energy space heating and water heating projects are discussed briefly in Appendix G. Further analysis and results of additional projects are being announced almost daily that will certainly add to these listed in the thesis. A lot of good sound information can be gained from studying the results so that the various difficulties encountered in these projects can be eliminated or minimized in future projects yet to be undertaken.

6. Solar Energy: Pro and Con

To the question "Should more money be mandated for solar energy research?" two experts commented:

> PRO. Professor Erich A. Farber, Director of the Solar Energy and Energy Conversion Laboratory, University of Florida.
>
> Through research we have to find better methods of converting solar energy, our largest and most permanent energy income, into the forms of energy that we use in our daily lives. This will free our fossil fuels (oil, coal, gas) for medicines, preservatives, pesticides, fertilizers and plastics, which are just as vital to our

survival. We should, however, not wait for the perfect answer, but put to work the knowledge which we have now for the conversions which make economic sense -- such as solar energy used for water-heating and cooling. We should utilize this nonpollutant source that belongs to all of us.

CON. Hans. A. Bethe, Professor of Physics, Emeritus, Cornell University

I do not believe the promise of solar energy is very great. Solar-energy utilization is not around the corner. To harness it for truly major energy production is exorbitantly expensive by any method now in sight -- and we will not become practical in this century, no matter how much we spend on research. However, solar-heating of water seems reasonable. For large-scale solar-energy power, it seems most promising to direct our efforts towards using the waste from farms, forests and cities. As one example, instead of discarding the stalks from wheat or corn, they could be fermented into substitutes for natural gas. [Ref. 57]

IV. APPLICATIONS OF SOLAR ENERGY

Increased interest has been widely expressed in the use of so-called "exotic" energy sources to replace or supplement dwindling supplies of fossil fuels. Figure 10 illustrates various sources of solar, lunar and other energy available for consumption. Direct uses of solar energy include the use of solar collectors, photovoltaic cells, and thermal processes. Indirect uses include wind generation, ocean-thermal,

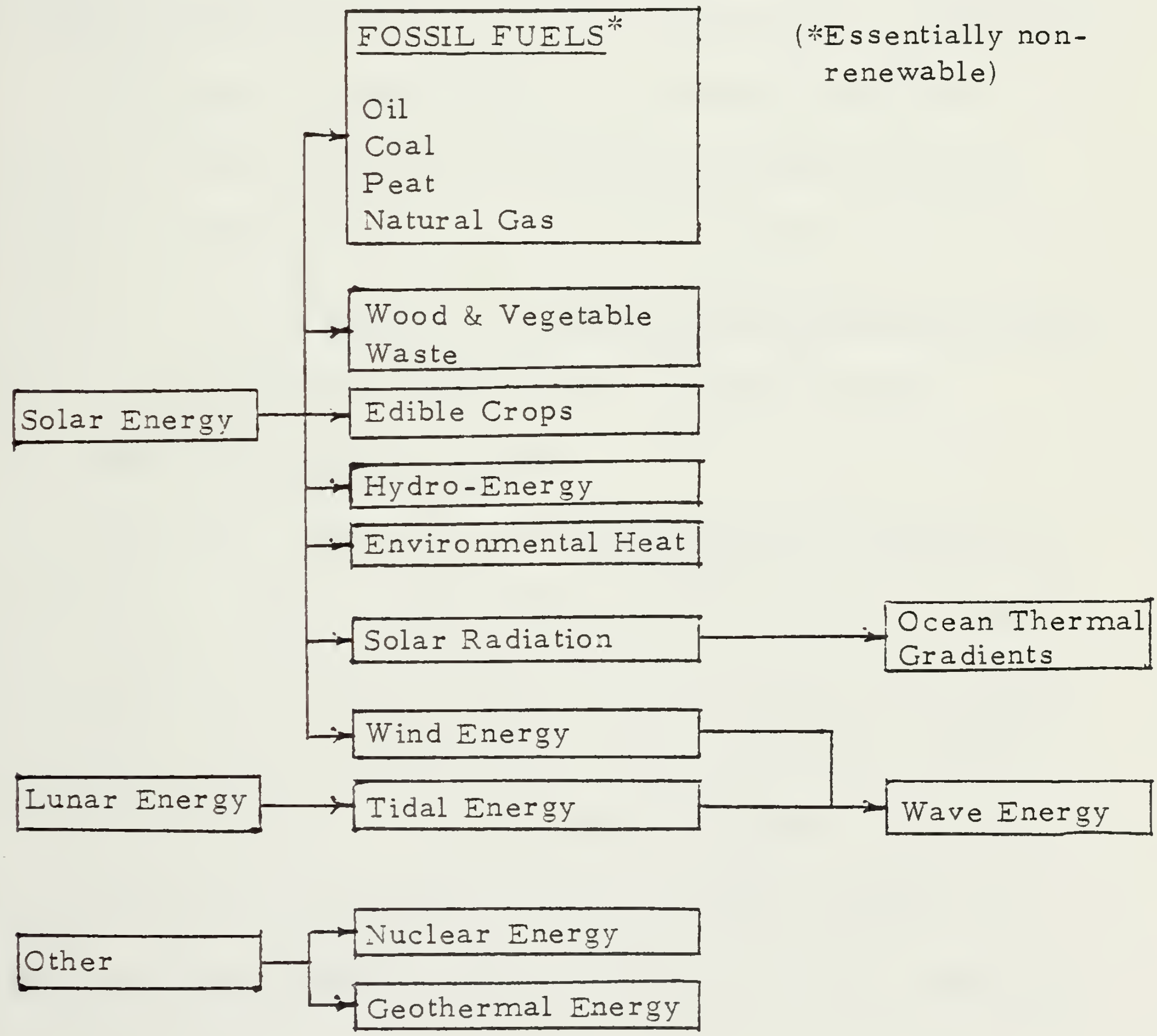


Fig. 10. The World's Sources of Energy (Source: Ref. 112).

bio-conversion, and waste-heat thermal gradients. Various applications of solar energy conversion to useful sources of energy to supplement or replace fossil fuel sources in the future are discussed in this Chapter.

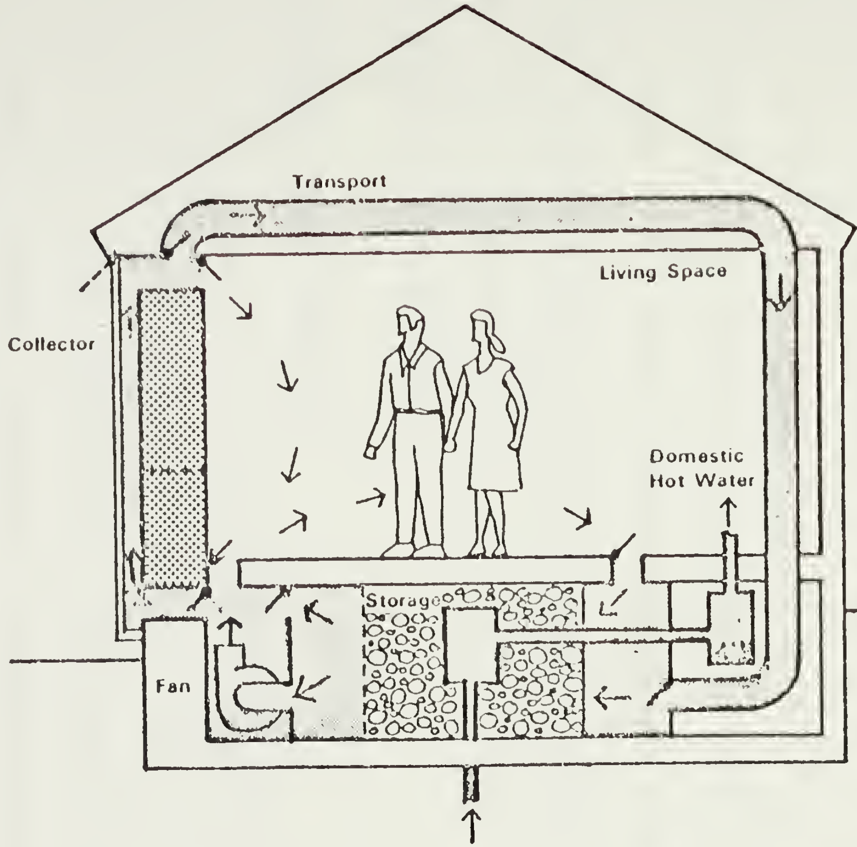
A. SPACE HEATING

1. Direct (or Passive) System

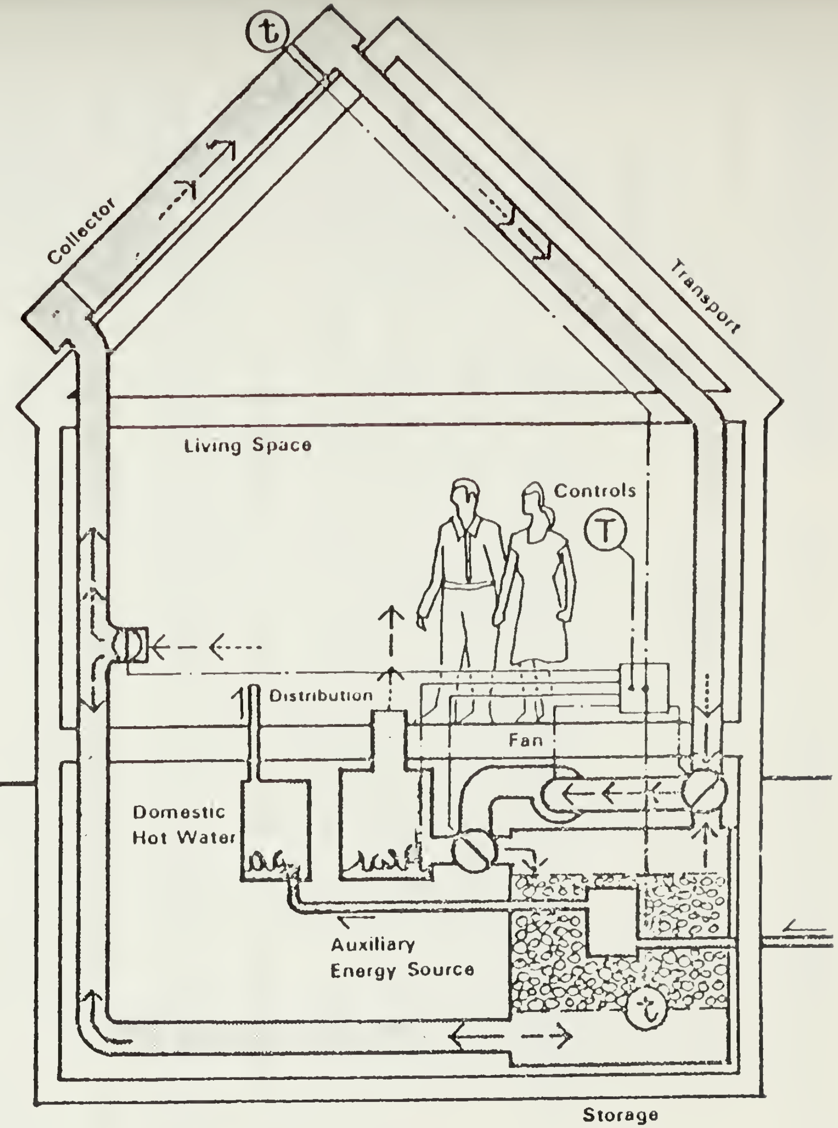
Direct solar is the most cost effective method for heating (and cooling). The buildings are designed so they accept or reject heat directly without the use of solar hardware systems. The energy storage and transfer system is often the structure's skin itself. It collects and radiates the energy throughout the building naturally. This type of system is best adapted in new construction. For further information refer to Chapter VIII - New Solar System Characteristics. Figure 11. A illustrates a typical direct (or passive) system.

2. Indirect (or Active) System

Presently, most solar space heating and water heating systems are of the indirect (or active) type. Indirect solar is a system in which the solar heat is received in collectors outside the building and transferred inside through ducts or pipes, with fans or pumps. These systems are used to a large degree in "retrofit" adaptions in existing buildings. For further information refer to Chapter VII -- Retrofitting System Characteristics -- and Chapter VIII -- New Solar



A. Direct (or Passive) System



B. Indirect (or Active) System

Fig. 11. Typical Types of Solar Heating Systems
(Source: Ref. 75).

System Characteristics. Figure 11. B illustrates a typical indirect (or active) system.

B. SPACE COOLING

The use of solar radiation for cooling, by means of thermal processes, is perhaps the least developed of all solar systems, although it has been demonstrated to be technically feasible for over one-hundred years. The oldest and most widely used cooling process is absorption refrigeration first demonstrated by Faraday in 1824. Another cooling process, using vapor jets to produce evaporation of fluids, such as water of fluorinated hydrocarbons, has also been demonstrated. Still another, the use of solar batteries to drive heat-pump refrigerators, is currently under study. [Ref. 20]. Further research and development (R &D) efforts are required to provide for a more economical and technological application of solar cooling. Figure 12 illustrates a typical solar heating and cooling system which uses water as the collector circulation fluid and a water tank for heat storage. The conventional furnace operates in parallel mode with the collector and storage unit.

C. SWIMMING POOL HEATING

The components of an active solar swimming pool heater are similar to those of the domestic hot water and active space heaters of the liquid type. (See Chapter III for a more detailed description of active heating systems). In general, all employ flat plate collectors

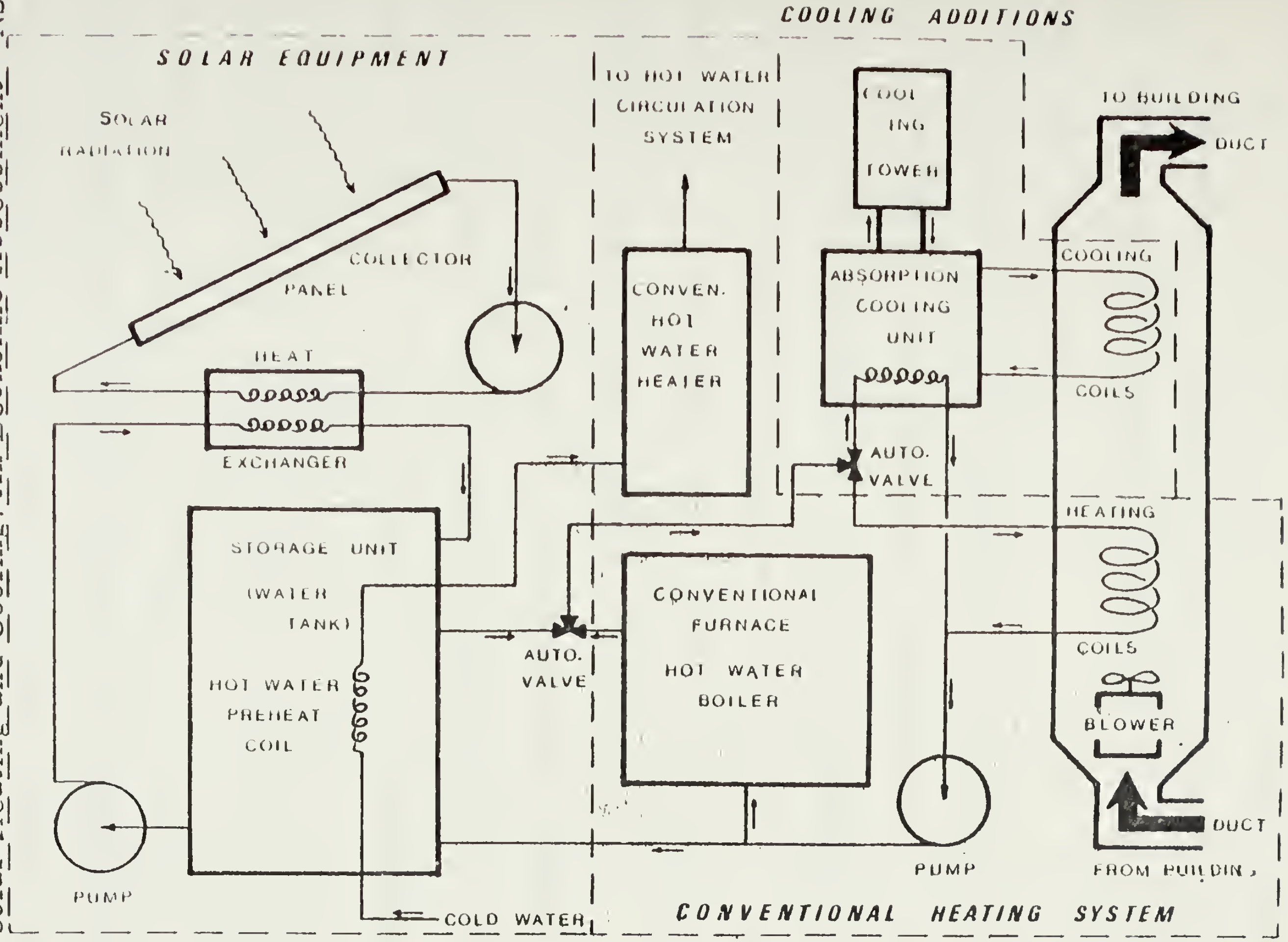


Fig. 12. Typical Solar Heating and Cooling System (Source: Ref. 111).

and the heat transfer medium is moved from collector to water storage areas by electric pumps. Swimming pool heaters raise the temperature of several thousand gallons of water only a few degrees, to around 80° F, but can operate at an efficiency of 70-80%. The pool temperature can be maintained on an average of 10° F above an unheated pool and can therefore extend the swimming season a couple of extra months in many areas of the country.

Solar pool heaters take advantage of the fact that solar collectors are more efficient when working at low temperatures. Collectors normally need not be glazed or insulated for swimming pool applications, which results in a simpler design that is far less expensive than collectors for space and hot water heating, which requires glazing and insulation to obtain a higher heating temperature.

The swimming pool itself can function as the thermal storage area, employing an effective thermal storage medium -- water. The pool can also serve as a collecting surface. Transparent pool covers, of various materials, are commercially available, and when used in conjunction with solar collector systems can contribute substantially to maintaining and raising water temperatures by "passive" means. Figure 13 illustrates a typical swimming pool schematic diagram using solar collectors and an auxiliary heater. Although solar swimming pool heaters have been demonstrated to be practical

and technologically feasible, one major drawback at the present time is that for the most part they are not economically feasible when compared with fossil-fuel fired heating systems.

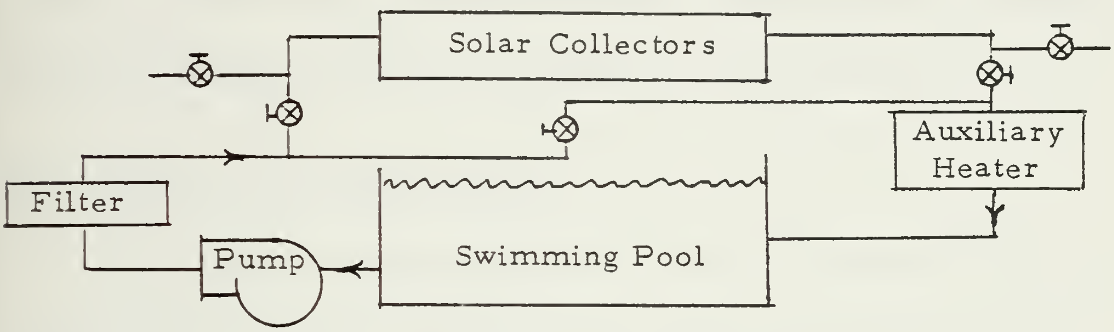


Fig. 13. Solar Swimming Pool Heater Schematic

D. COOKING

Several solar cookers have been described in India, Lebanon, Japan and the United States. Several practical applications have already been designed. These are: (1) a collapsible umbrella type made with aluminum Mylar designed by George O. G. Löf; (2) another type made from sheet aluminum is being sold by a sporting goods store -- in fixed parabola form and in collapsible sections; (3) a small solar oven with reflecting side plates and glass cover plates has been designed by Maria Telkes; and (4) a small parabolic mirror with a small cooking pan attached above it built with $12 worth of plywood, sheet aluminum and sun control film -- a device that can barbecue a stick of meat in five minutes (teriyaki beef). [Refs. 27, 28].

E. BAKING

One type of solar oven uses metallic wings to reflect sunshine through a double glass cover into an insulated and blackened box. If the oven is kept pointed toward the sun during the midday hours, the interior temperature can readily attain a temperature of 350-400° F which is adequate for most baking operations. [Ref. 52].

F. DISTILLATION OF WATER

This system is technologically feasible, but the problems are to lower costs and find suitable locations where solar distillation is economically competitive or the needs are sufficiently compelling. Fresh water is ordinarily so cheap that demineralized salt water cannot compete economically. There are several ways in which it is possible to obtain fresh water from salt water, including distillation with solar energy and with single or multiple condensation stills, vapor compression, centrifugation, ion exchange, and electrodialysis. These have been discussed at many symposia and presented in various papers and other sources. [Refs. 20, 29, 30].

G. BIOCONVERSION

The Energy Research and Development Administration (ERDA) program of bioconversion to fuels is currently working to establish the commercial practicality of producing significant quantities of plant materials at feasible costs. This technique of using solar energy

is to accentuate the natural processes of photosynthesis in plant life. The goal is to convert these materials and other organic products now considered wastes into clean fuels. The four primary sources of materials currently being examined are: (1) urban solid wastes, (2) agricultural residues, (3) terrestrial crops and (4) marine crops. End products that may result include synthetic fuels, alcohol fuels, solid fuels, heat, electricity, ammonia nitrogen fertilizer, and petrochemical substitutes.

The economic analysis of bioconversion has one interesting aspect that should be explored. If the entire cost of production has to be recovered by the sale of the end products, solar energy might find it difficult to be economically competitive with conventional fossil fuels. But, if a portion of the cost is charged to environmental protection and disposal of wastes, or if fossil fuels begin to disappear in significant quantities through depletion, the prospects for solar energy bioconversion systems seem more promising. [Ref. 11].

One method of bioconversion would use the idea of trapping solar energy by growing algae or other plants, such as giant kelp as an ocean energy crop, which could be used as food or burned for energy. A 7-acre kelp farm off the coast of California is being studied to determine operating and performance characteristics of kelp beds on floating structures. The Cornell Workshop has viewed the scheme of trapping energy by growing algae or other plants as unresolved, but has

pointed out that the possibilities should be explored in a coherent solar energy program. [Refs. 11, 96].

Synthetic fuel development is destined to play a major future role in our Nation's energy future (see Chapter V for its role in our National Energy Program). Some professors at Texas A&M College believe they might just have the answer to the Nation's fuel problems. They have researched some 400,000 German technological documents that were captured at the end of WWII. Ninety percent of the documents have never been looked at since they were taken, but they contain the records of the German WWII synthetic fuel industry "... right down to the repair manuals." At Hitler's orders the Germans had begun intensive work on synthetic fuel in 1936, but American experts at the time had dismissed their efforts as a bluff. It appears as though now that the Germans just might have hit upon a major technological find in the development of synthetic fuels. Further review of these records should assist the current U.S. search for processes to develop synthetic fuels. [Ref. 97].

H. AGRICULTURAL CROP DRYING

Drying corn on top of an academic building at Clemson University may seem a bit strange, but when Professor Harold Allen, agricultural engineer at Clemson, explains what is happening, it all makes good sense. Professor Allen is interested in the possibilities solar energy and heat pumps hold for farmers who are now drying grain with natural

gas and other fossil fuel-derived energy sources. Therefore, ... the roof of McAdams Hall seemed to be the best spot around for our research," he says, "because it gets more uninterrupted sun than places on the ground that are shaded part of the day."

His research is involved with investigating the economics of solar energy to see if it is practical for farmers to invest in solar equipment for grain drying. Right now the answer appears to be no. Commercial solar equipment can cost from $8 to $30 per square foot (calculated on the basis of the square footage of solar collector required to heat the system). Allen indicates that "in view of the relative 'cheapness' of natural gas, this would be unprofitable for the farmer even if there were such equipment on the market -- and there isn't." The grain drying model is called a "solar assisted" system because it combines the energy derived from four solar panels with a backup "heat pump" unit capable of generating 4,000 Btus of heat energy per hour. The corn to be dried is poured into a bin located beside the collectors and collector ducts carry heat into the bin. [Ref. 98].

I. DOMESTIC WATER HEATING

Considering all the various types of solar energy systems available on the market today, the one system that solar energy experts recognize as having the most immediate economical potential is solar water heating. There has been perhaps more recent interest in solar

water heating than any other application. Recent studies have shown solar domestic water heating is economically attractive in most areas of the U.S. on a life-cycle basis when the alternative is electrical water heating. [Refs. 31, 32, 33]. In addition, there are several other references that provide useful information on solar water heating application in facilities. [Refs. 34, 35, 36]. Solar water heating has several major advantages that make it a worthwhile consideration in most facilities today. These are:

1. Universal Need

All commercial/industrial and residential facilities in advanced civilizations around the world use hot water for one purpose or another -- shaving, bathing, washing clothes, etc.

2. Year Round Use

Hot water for dishwashing, clothes washing, cooking, shaving, showering, bathing, etc., is used the year round -- it is not a seasonal use like space heating or cooling.

3. State-of-the-Art Development

Solar water heaters have been demonstrated to be both technologically feasible and economically attractive for many years. In fact, they have been used in the U.S. since before 1900, and by the mid-1950s there were more than 60,000 solar water heaters (mostly the thermosyphon type) in operation in Miami, Florida, alone. Solar water heaters were the first to catch the manufacturer's imagination

as they were small, relatively inexpensive, and tangible products, which could be "mass-produced and sold 'over the counter'." They fit the pattern of the domestic appliance market. [Refs. 39, 93].

4. Retrofitting or New Facility Use

Solar water heating should be an attractive proposition, as they can easily be retrofitted into existing facilities as well as designed into new facilities yet to be constructed. Since it appears that most of the solar energy facilities of the future have already been constructed today, the retrofitting concept should be considered for existing facilities.

5. Economically Viable

Solar water heating is the most economically viable of all available solar energy systems. [Refs. 34, 35, 36].

6. Demand Constant

The demand for hot water is relatively constant throughout the year.

7. Sized More Closely to Demand

While solar space heating and cooling systems must handle extreme loads only a few days out of the year, they must be sized to meet these extremes. A solar water heater, on the other hand, will have roughly the same load requirements day in and day out. By avoiding problems of fluctuating loads, the solar water heater can be sized much more accurately and economically to meet the demand.

8. Ecologically and Aesthetically Attractive

Solar energy is environmentally clean and non-polluting. Because of its small size, the solar water heater can be aesthetically blended into the design of a new facility or retrofitted into an existing facility without difficulty.

9. Little Space Requirement

The solar water heater is relatively small when compared to space heating and cooling -- either conventional or solar systems.

10. Lower Utility Bill

The cost of hot water heating accounts for up to one-third of the annual heating bill, or more, depending on the climatic conditions and location. A well designed solar water heating system can provide between 65% and 90% of the total water-heating demands of the average facility. In addition, the payback period of the solar water heating system is approximately 10 years, which means since the average life of the solar energy system is approximately 20-25 years, there is a period of between 10 and 15 years where the solar energy system provides almost pure profit to the owner. [Refs. 24, 37].

11. Lower Operation and Maintenance Costs

Operating costs are made up of the day-to-day costs for maintenance, repairs, and fuel costs. Based on current information and experience, it may be reasonable to disregard these costs from a practical standpoint. The fuel -- sunlight -- is free. Estimates of

the annual maintenance costs run less than 2% of the total initial installation costs. [Ref. 3].

12. Substitute for Natural Gas

Currently the energy used for space heating and cooling and water heating in Navy family housing, for example, is highly dependent on fuel oil (26%) and natural gas (27%). Table IV shows a breakdown of energy sources used in Navy family housing.

Table IV. Breakdown of Energy Sources in Navy Family Housing

SOURCE	PERCENT USE	HOW USED
Electricity	40%	Primarily air conditioning
Fuel Oil	26%	Primarily water and space heating
Natural Gas	27%	Primarily water and space heating
Propane	1%	Primarily water and space heating

(Source: Ref. 40)

Currently DOD discourages the direct use of electricity for water heating and space heating -- due primarily to the high cost of electricity. [Ref. 40]. However, if natural gas reserves decline further, the Federal Power Commission's "Curtailment Priority System for Use in Times of Natural Gas Shortage" could reduce the availability of natural gas at military bases. Should this happen, only limited choices now exist for the Navy to switch over to other energy sources. Coupled with shortages in fuel oil and low use of

propane, the Navy has very little choice but to switch over to electricity -- the most expensive energy source. This is one area of solar energy development where the Navy might be able to gain rich dividends with its installation in Navy facilities -- commercial, industrial and residential. Further exploration of this solar energy application is contained in Chapters VII and VIII. An economical evaluation of solar water heating systems is contained in Appendix B and a summary review of several solar water heating projects is included in Appendix G.

V. NATIONAL SOLAR ENERGY PROGRAM

Energy has become and will continue to be a major and complex area of Federal government concern. This nation, and indeed all the nations of the world, are confronted with a long-term critical problem of assuring that an adequate supply of energy is available to meet even the most essential needs. The nation has experienced, contemporaneously, rapidly growing demand for all types of energy in the face of increasing problems concerning environmental costs and very substantial depletion of the nonrenewable energy sources that the nation has historically depended on -- coal, oil and natural gas. These problems facing the nation today present a real challenge to the Federal government to develop alternative energy sources. The possibility of another supply interruption -- like the Arab oil embargo in 1973-74 or the natural gas shortages in 1976-77 -- will continue for the foreseeable future. Should it occur, the U.S. must be prepared with alternative sources of energy.

With the exception of several small research projects and work on solar distillation of salt water, supported by the Department of the Interior, very little attention was given to the use of solar energy by the Federal government prior to the mid-1950s. This Chapter reviews the development of a national energy plan and the emergence of a

national solar energy program with emphasis on national level goals and funding.

A. FEDERAL ROLE AND STRATEGY IN ENERGY RESEARCH AND DEVELOPMENT

The proper Federal government role in energy R&D is:

> ... To concentrate on research and on technologies that have a high potential for energy production for or savings to the Nation, but that also have such technical risk or periods of development that the private sector would not normally pursue them on its own or in a timely manner. This role is one that will support, encourage, and supplement, but not supplant private sector activity. Federal efforts are less appropriately applied where the technical risk is low, development time is relatively short, or an intimate knowledge of the market is required. [Ref. 89].

The program of energy R&D proposed in the President's FY 1978 Budget recognizes the growing demand for energy that the Nation will continue to experience in order to maintain its economic strength. Energy conservation efforts will formulate a major portion of the energy program. The expected demand requires that the Federal government's energy R&D program concentrate on technologies which will not only be cost-effective when developed, but also have the potential for major contributions to meeting the Nation's needs.

Coal and nuclear energy will occupy a prominent role in the decades to come. [Ref. 89]. A change, however, in the energy base from fossil fuels to alternative energy sources is not a matter of choice which can be carried out according to the economic and social pressures of the time. It needs much preparation over many decades.

> America's hope for long-term economic growth beyond the year 2,000 rests on renewable and virtually inexhaustible sources of energy, such as solar and geothermal energy. The Government will promote aggressively the development of renewable sources. [Ref. 7].

This statement -- from President Carter's proposed energy plan -- expresses the Commander-in-Chief's concern about the use of solar energy and the Federal government's role in developing such "renewable and inexhaustible" resources in the future. Just how DOD and the Navy fit into the overall national energy plan will be the primary areas of concentration in the remaining Chapters of this thesis. No attempt will be made to duplicate that which has already been so painstakingly accomplished, but rather to compliment it -- to build upon the foundation already constructed by bringing the research that has been found in numerous sources up to date in one concentrated source for future reference.

B. INITIAL INSTITUTIONAL AND GOVERNMENT INVOLVEMENT

At the institutional level, the first significant basic solar research support came from the Cabot Fund given to the Massachusetts Institute of Technology and Harvard University about 1934-35. Work was carried out on house heating, flat-plate collectors and photochemical possibilities. Active practical development and direct use of solar energy followed in the 1940s by Drs. Maria Telkes and George O. G. Löf, two early pioneers in solar development in the United States, both of whom did

some of their early work at M.I.T. A grant from the Guggenheim Fund and additional substantial support from the Rockefeller Foundation, starting in 1955, have been primarily responsible for further solar research and development at the University of Wisconsin, with particular emphasis on application of solar in non-industrialized countries. [Ref. 20].

The Federal government's first big step into the solar energy picture began in the 1960s when it spent vast sums of money on the development of solar cells to power space vehicles in the NASA space program. The first Federal government funding of solar research, other than for the space program, was in 1970, and amounted to just over $1.0 million. In 1972 funding amounted to $1.7 million; in 1975 $50 million; in 1976 $180 million; and by 1977 the amount was programmed for over $183 million in solar energy RD&D. [Ref. 6, 44]. Although these funds are relatively small amounts in the total Federal energy RD&D budget, they have provided at least an impetus to move solar energy out of the hands of the hobbyist/inventor to the first level of practical, widespread use in the United States.

President Nixon, in his 29 June 1973 energy message, established "Project Independence" which initiated a National goal of total energy self-sufficiency by the mid-1980s. The first solar energy research directions were given to the now defunct Atomic Energy Commission (AEC). The AEC was later replaced by the Energy Research and

Development Administration (ERDA) which was established in 1975. ERDA has been tasked to develop a comprehensive energy program in cooperation with other Federal agencies and industry to promulgate solar energy and other alternative energy sources to promulgate this goal of self-sufficiency. The first ERDA funding in 1973 in the amount of $10 million was established to support projects that would either support the goal to achieve energy self-sufficiency or support RD&D effort to provide new options -- e.g., solar energy -- for meeting our future energy needs. [Ref. 54].

The first Federal government solar energy powered building located in Manchester, N.H., was completed in August 1976 at a total cost of $8.7 million. The solar equipment alone cost $116,000 and was funded under a grant from ERDA. The system is expected to provide, on the average, 20 to 30% of the energy required for hot water and heating and cooling. The Commerce Department's National Bureau of Standards will evaluate the building's performance for a period of three years. Occupants of the General Service Administration's building include 400 employees of the Veterans Administration, Federal Energy Administration, and Department of Defense. [Ref. 113].

C. SUMMARY OF FEDERAL LAWS APPLICABLE TO SOLAR ENERGY

Since May 1974, when the "Federal Energy Administration Act of 1974" became public law, seven major pieces of solar energy-related legislation have been enacted. They are chronologically:

1. Federal Energy Administration Act of 1974 - Public Law: 93-275. Approved April 7, 1974.

2. Solar Heating and Cooling Demonstration Act of 1974 - Public Law: 93-409. Approved September 3, 1974.

3. Energy Reorganization Act of 1974 - Public Law: 93-438. Approved October 11, 1974.

4. Solar Energy Research, Development, and Demonstration Act of 1974 - Public Law: 93-473. Approved October 26, 1974.

5. Federal Non-nuclear Energy Research and Development Act of 1974 - Public Law: 93-577. Approved December 31, 1974.

6. Energy Policy and Conservation Act - Public Law: 94-163. Approved December 22, 1975.

7. Energy Research and Development Administration Appropriation - Public Law: 94-187. Approved December 31, 1975.

In the sections of these laws that deal specifically with solar heating technology applications, the thrust is to provide for demonstration of its practical use to potential consumers and producers. In addition, a significant emphasis is placed on research of solar systems, their economic, social, and environmental aspects, and on the dissemination of research results. Following enactment of the "Energy Reorganization Act of 1974," ERDA has been the lead Federal agency for solar energy research, development, and demonstration.

ERDA's "National Program for Solar Heating and Cooling," emphasizes the first-cost hurdle of solar heating technology as a major constraint in its widespread application. It basically suggests the need

to test and develop technical innovative approaches to lowering the cost and producing higher performance, with particular emphasis on "retrofit" systems in existing facilities. Retrofitting will be discussed in more detail in Chapter VII of this thesis.

In another area of the Federal government, the Research Applied for National Public Technology Projects Office contracted for three commercial companies -- General Electric, Westinghouse, and TRW -- in October 1973 to conduct feasibility studies for the use of solar heating and cooling in buildings and to include environmental, sociological, technological, and economic factors in the analysis. The results, known as the Solar Heating and Cooling Buildings (Phase 0) Reports, were completed in May 1974. The reports concluded that solar energy had the potential for making a significant positive contribution to the Nation's economy by the year, 2000. Another conclusion indicated the greatest market potential in the private sector would be found in the new construction arena, and not in retrofitting existing housing units. This conclusion is somewhat at odds with the previously mentioned ERDA "National Program for Solar Heating and Cooling." [Ref. 54].

The most recent boost for solar energy was from President Carter in his energy address to Congress on 20 April 1977. [Ref. 18]. He charged the Federal government "... to set the example" ... and indicated he would issue an Executive Order establishing "... strict conservation goals for both new and old Federal buildings ..." -- a

45% increase in energy efficiency for new buildings and a 20% increase for existing buildings by 1985. He further indicated he wanted to set a national goal for the use of "... solar energy in more than 2-1/2 million homes ... by 1985," a figure which Dr. James Schlesinger, the first Secretary of Energy, has since revised downwards to about 1.3 million homes. [Ref. 55].

In order to boost the use of solar energy, and in response to President Carter's energy message, the Federal government, through the Department of Housing and Urban Development (HUD), plans to help buy solar water heaters for 10,000 homes in the U.S. and will provide $400 each to some 10,000 homeowners and builders in 10 states who wish to install solar water-heating systems in their homes. This project, under a $4.6 million solar-testing budget, will provide outright grants to homeowners to cover about one-half the material costs of the solar water heaters -- it will not include installation expenses. These grants represent a major expansion of HUD's solar heating and cooling demonstration program. [Ref. 56].

D. NATIONAL ENERGY PLAN

As part of the new energy initiatives sought by President Carter, Congress recently approved the establishment of a new Cabinet level Department of Energy (DOE) headed by the first Secretary of Energy, Dr. James R. Schlesinger which began operation on 1 October 1977 with about 20,000 employees and a budget of about $10.6 billion.

The new Energy Department has as its core three existing agencies -- the Federal Energy Administration (FEA), the Federal Power Commission (FPC), and the Energy Research and Development Administration (ERDA) -- and will consolidate the energy functions of some 50 bureaus and agencies that have been scattered throughout the Federal government. Two of the core agencies, FEA and ERDA, are in fact the result of early hesitant steps by the Federal government to meet the energy problems encountered after the Arab oil embargo in 1973. The third, the FPC, dates back to the 1930s, when it was created by the Federal government when concern developed over the monopoly of electric utilities. The new DOE will administer the Carter Administration's national energy plan, which is working its way through Congress. [Refs. 65, 81].

The formal National Energy Plan proposal submitted by President Carter to Congress on 29 April 1977 outlines the President's stand on a national energy policy. Exhibit I contains a facsimile copy of President Carter's introductory comments to the National Energy Plan. The plan proposes several strategies and objectives and lists several important salient features:

1. Strategies and Objectives

   a. As an immediate objective, that will become even more important in the future, to reduce dependence on foreign oil and vulnerability to supply interruptions;

b. In the medium term, to keep U.S. imports sufficiently low to weather the period when world oil production approaches its capacity limitation;

c. In the long term, to have renewable and essentially inexhaustible sources of energy for sustained economic growth.

2. Salient Features

a. Conservation and fuel efficiency;

b. Rational pricing and production policies;

c. Reasonable certainty and stability in government policies;

d. Substitution of abundant energy resources for those in short supply;

e. Development of non-conventional technologies for the future.

E. NATIONAL SOLAR ENERGY PROGRAM

As a result of the Federal Laws passed between 1973 and 1977, and the support of the current Administration, a major National Solar Energy Program is underway. In cooperation with ERDA, other Federal agencies -- including the National Bureau of Standards (NBS), National Aeronautics and Space Administration (NASA), General Services Administration (GSA), Department of Housing and Urban Development (HUD), and the Department of Defense (DOD) -- have contributed to the publishing of The National Program for Solar Heating and Cooling of Buildings. Major elements specified in this Program include:

1. Demonstration of solar technology in both commercial and residential buildings, initially using available systems.

2. Development of solar technology to support such demonstrations, initially using available sub-systems and components.

3. Research and development of advanced heating and cooling technology for possible use in later stages of the demonstration.

4. Development of standards and certification procedures for solar energy systems.

5. The dissemination of information on the results of the efforts above.

All of these program objectives, along with increased Federal government funding and support, should stimulate individuals and industry into developing practical applications of solar energy. The overall thrust of these programs is to expand the technical base and drive solar energy costs down through stimulation of an industrial market base for solar energy products and systems.

The Energy Research and Development Administration (ERDA) is currently sponsoring commercial and non-residential grants as part of the National Solar Demonstration Program. Under this program, grants are provided to builders, architects, companies, municipalities or individuals to help cover the cost of installing solar systems in non-residential building projects. Results of building projects to date are summarized in the National Program for Solar Heating and Cooling of Buildings: Project Data Summaries, Volume I. The Federal Buildings Program as part of the National Solar Demonstration Program,

includes residential and non-residential structures. The residential demonstration projects, are implemented primarily on DOD properties, while the non-residential projects apply to all Federal agencies.

Military personnel interested in participating in the National Solar Demonstration Program first contact their appropriate military housing officer (NAVFAC in the case of Navy facilities) who then contacts DOD. DOD then submits proposals to ERDA's Division of Solar Energy for review and support. A description of Navy submitted solar projects is included in the National Program for Solar Heating and Cooling of Buildings: Project Data Summaries, Volume I, Commercial and Residential Demonstrations. [Ref. 114].

F. NATIONAL SOLAR ENERGY PROGRAM GOAL AND EMPHASIS

The overall goal of the national solar energy program is to develop and demonstrate at an early date those solar energy systems and applications that are economically attractive and environmentally acceptable for significantly supplementing U.S. energy resources. In meeting this goal the solar energy program has been organized in four major subprograms, involving R&D on three specific solar technologies and their applications. These four subprograms are: (1) thermal applications; (2) solar electric applications; (3) fuels from biomass; and (4) technology support and utilization.

The major emphasis on solar energy development in 1978 will be placed on conducting research and development (R&D) that may lead

to technological and economic breakthroughs for solar electric technologies. The approach includes development of several technologies for commercial assessment: wind systems as an initial contributor; photovoltaic and solar thermal electric systems for peak and intermediate electric load applications; and ocean thermal for base load in the long term. Conservation R&D will look at electric energy systems and energy storage technologies; e.g., whether centrally located (energy parks) or dispersed (solar heating and cooling, windmills, fuel cells, or battery storage) are more optimal, reliable, efficient and environmentally acceptable. Additional emphasis in the basic energy sciences program will be placed on materials science research of potential value to solar technology and studies in the area of solar photochemistry under the overall guidance of ERDA. [Ref. 90].

G. NATIONAL SOLAR ENERGY PROGRAM FUNDING -- 1978

Data and analyses relating to the energy budget of the Federal Government for 1978 are published in six documents:

(1) The Budget of the U.S. Government, 1978;

(2) The Budget of the U.S. Government, 1978 -- Appendix;

(3) Special Analyses, Budget of the U.S. Government, 1978;

(4) The U.S. Budget in Brief, 1978;

(5) Issues, '78;

(6) The Budget of the U.S. Government, 1978 -- Supplement.

These documents are available for purchase from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, or may be found in many Public Libraries in the U.S.

Areas of importance to funding for solar energy and other energy alternatives programs for 1978, outlined in Issues '78, [Ref. 89], are summarized below:

1. Highlights of R&D in the 1978 Budget:

In the Energy Research and Development Administration, funding will be increased to accelerate work on technologies to use fossil fuels in an environmentally acceptable manner and at reasonable costs. Research and Development on solar, geothermal, and conservation technologies will be stepped up (as in previous years) while the nuclear R&D program will emphasize efforts to dispose of nuclear wastes and to prevent diversion of materials that could be used to build weapons. Specific energy R&D programs are discussed at greater length in the Issues '78 document.

2. Primary Non-R&D Actions:

The primary non-R&D actions to be taken in 1978 are energy price deregulation and reasonable, stable environmental standards. Thus, it is important to consider energy R&D as only part of the solution to the Nation's energy problems and not the solution.

3. A National Marketplace for Energy:

Unlike Defense R&D where there is only one customer -- the U.S. Government -- for the results of the R&D, energy R&D must

meet the needs of a large and diverse number of organizations and individuals who will produce, market and use these new technologies. Also, unlike new DOD technologies -- where cost may be subordinated to other requirements -- new energy technologies must be competitive or they will not be manufactured, marketed or sold in the marketplace.

4. Long-Term Energy Potential Technologies:

There are several technologies, such as energy conservation and solar energy, which have been selected for Federal R&D support because of their long-term potential. The Federal Government feels that undue support for these technologies is not appropriate because many would not be competitive for widespread application and do not have the potential to become major contributors in the near term.

5. Summary of Federal Energy R&D Programs:

During FY77, solar energy R&D made up approximately 6.25% of the total Federal energy R&D program; in FY78 this figure rises to about 6.51%. In terms of dollars, FY77 equates to $183 million out of a total of $2,927 million; FY78 equates to $235 million out of a total of $3,655 million. See Table V for further information. [Ref. 89].

6. Solar Energy R&D Budget:

The 1978 Budget proposes outlays of $235 million for solar energy R&D, an increase of 28% over the FY77 level. Recognizing the rapid development of the solar heating industry and the current

Table V. Federal Energy RD&D Program Monetary Outlays

Direct Energy R&D	FY 1977	FY 1978	% INC.
	(Outlays in millions of $)		
ERDA, total	2193	2779	27
Fossil	445	500	12
Solar	183	235	28
Geothermal	49	68	39
Conservation	120	140	17
Fusion	322	431	34
Fission	717	879	23
Fuel Cycle/Safeguards	227	350	54
Enrichment R&D	130	176	35
EPA (Environmental Control Tech.)	38	60	58
NRC (Regulating Research)	112	134	20
DOI (Mining)	63	64	--
Other	8	5	--
Total Direct Energy R&D:	2414	3042	26
Supporting R&D	479	578	21
Energy Related	34	35	--
Grand Total:	2927	3655	25

(Source: Issues '78, Ref. 89).

availability of solar heating technology, greater emphasis will be placed on development and demonstration of solar cooling with reduced emphasis on solar heating. For solar electric technologies, a greater emphasis is being placed on research, experiments, and studies that could lead to technological and economic breakthroughs (e.g., novel materials and devices for photovoltaics), and a lesser emphasis is on accelerated demonstration of large-scale hardware.

H. STATE SOLAR ENERGY LEGISLATION INITIATIVES

The importance of Federal government incentives, development, and initiatives is of paramount importance in setting the example for the Nation, particularly in solar energy areas. Also, the importance of solar energy to global and national welfare is more than adequate justification for the American people to demand better than equal treatment for its promotion. However, the Federal government cannot and should not provide the only incentives for solar energy use. State and local governments also have a vested interest in the well-being of the nation, and should be involved in its future plans and alternative energy solutions. While no direct current legislation to benefit solar installations has yet been enacted at the Federal government level, at least 35 states have already enacted some form of legislation or are considering solar-related measures. A sample of recently enacted Laws at the state level are listed below for informational purposes:

1. Colorado - In 1975 provided legislative recognition of solar easements (S. B. - 95);

2. Oregon - In 1975 mandated consideration of access to incident sunlight in any comprehensive plan, zoning, subdivision, or other land use ordnance (H. B. - 2036);

3. Florida - In 1974 amended the state building code to require that plumbing fixtures in new single-family residences be compatible with solar heating systems (S.B. - 158);

4. Minnesota - In 1975 authorized building code energy standards which facilitate solar-collector system construction (H. - 923, amended: Laws of 1974, c. 307);

5. California - Solar Energy Tax Credit - 1976 Income Tax Form 540 Instructions, p. 3, "For taxable years beginning in 1976, a tax credit for the cost of solar energy device(s) is available to individuals in the amount of 10% of the cost of such device(s) including installation charges . . . ."

6. Georgia - A statewide constitutional amendment passed in Georgia in December 1976 authorized a county or city government to exempt from property taxes any solar heating or cooling systems, as well as machinery and equipment used directly in the manufacturing of solar heating and cooling systems. The 1976 Georgia legislature also passed a measure exempting solar equipment from state sales and use tax.

(For additional information on State solar energy legislation, refer to References 53 and 88.)

VI. DEPARTMENT OF DEFENSE AND NAVY SOLAR ENERGY ROLES

A large Federal government and civilian research, development and demonstration (RD&D) effort has been mounted to meet major solar energy problems that exist at the national level. The Department of Defense (DOD) and the Department of the Navy clearly should not want to "duplicate" any of that effort; but, they should participate in the various national programs to learn what is currently going on and take advantage of any major RD&D advances that may come out of these efforts. In order to determine what the DOD or Navy role in the nation's overall solar energy picture should be in the future, it is necessary to first review how current Laws and directives govern a portion of their involvement.

A. DEPARTMENT OF DEFENSE SOLAR ENERGY ROLE

Recently enacted Laws and directives currently govern development and demonstration of solar energy projects in the United States and directly impact on DOD activities. These include:

1. Public Law 93-409 -- The Solar Heating and Cooling Act of 1974

This Act provides for the "demonstration within a three-year period of other practical use of solar heating technology, and to provide for the development and demonstration within a five-year period

of the practical use of solar heating and cooling technology." This Act further provides for the participation of DOD in demonstrating solar heating and cooling systems "... in a sufficient number of different geographical areas under varying climatic conditions to constitute a realistic and effective demonstration in support of the objectives of this Act.

2. Public Law 93-473 -- The Solar Energy Research, Development, and Demonstration Act of 1974.

This Act declared a policy to "... provide for the development and demonstration of practical means to employ solar energy on a commercial scale ..." and also encouraged DOD participation.

Both Acts involve DOD in solar energy RD&D efforts primarily because of its massive real estate holdings in industrial and residential assets and research facilities. DOD's initial attention was directed toward residential housing -- DOD holds an inventory of over 320,000 eligible units of family housing, not including Bachelor Officer or Enlisted Quarters. [Ref. 104]. Under these two Acts, a Federal agency -- like DOD -- cannot itself produce a commercial product, but it can sponsor a program with industry that will produce a commercial product.

3. Military Construction Authorization Act (FY78).

The Department of Defense has recently asked Congress for authority to increase cost and square footage limitation for military family housing to enable the Services to use solar heating and cooling

in certain construction projects. This request was contained in the Fiscal Year 1978 (FY 78) Military Construction Authorization Act, and, if approved, will apply to previous military programs also. [Ref. 61]. Additional funds will undoubtedly be requested and added in the future as a result of further efforts by the Carter Administration to limit the use of conventional fossil fuel consumption through energy conservation measures and the development of alternative energy sources -- e.g., solar energy.

4. Energy Conservation Program (ECIP).

In an attempt to encourage further interest in solar energy projects, the Assistant Secretary of Defense, for Installations and Housing (I&H), issued a memorandum for DOD activities on 24 March 1977, concerning the Energy Conservation Investment Program (ECIP). This memorandum amends the basic ECIP Program accordingly:

> Amortization. Projects must amortize within 6.0 years except for solar energy projects. PL 94-431, Military Construction Authorization Act, 1977, recognizes and encourages solar energy projects. Therefore, solar energy projects, while they must be self-amortizing, are exempt from the 6.0 payback requirement and will be considered on a case-by-case basis. [Ref. 62].

The primary purpose of the ECIP Program, and subsequently the reason it doesn't compete with other military construction projects, is to reduce DOD's energy consumption and utility costs. The technology base being developed in various energy conservation and power systems coupled with RD&D efforts in solar energy projects, all

optimized for performance, reliability, operating criteria, and economics, consistent with the national energy policy, will provide a means for DOD to achieve its own goals of self sufficiency, lower utility costs, and maintain its operating posture in our nation's defense. The Navy can and will play a significant role in helping DOD attain its goals. The Navy's specific role in the overall energy plan will be discussed in the next Section of this Chapter.

5. DOD Military Services Solar Energy Participation

In support of the National Solar Energy Program initiated by the Federal government, the military Services are pioneering the installation of solar heating in family housing units. For example, the U.S. Army Corps of Engineers has awarded a contract for the construction of 652 family housing units at Fort Polk, Louisiana, 40 of which will have solar-assisted heating and cooling units. At Gila Bend, Arizona, the U.S. Air Force is preparing to construct 40 solar heated and cooled housing units. The U.S. Navy will construct 20 solar-operated houses at Newport, Rhode Island. The U.S. Marine Corps has no solar housing units planned for this year.

In addition, a new approach to large scale solar power development is under initial investigation. It is based on chemistry and is called SOLCHEM. Naval Research Laboratory scientists initiated SOLCHEM more than four years ago as a new approach to harnessing the sun's energy. In this project, many individual collector dishes

track the sun, reflecting intense sunlight onto a chemical convertor at nine focal points. In the process, solar heat is turned into chemical energy. Energy accumulated during the daytime is stored in large tanks to be continuously available 24-hours-a-day -- no matter what the weather conditions. In fulfilling the Federal government's part in the development and demonstration of renewable energy sources, much of the know-how about solar energy will come through the on-going R&D programs of DOD's military Service components. [Ref. 8].

B. DEPARTMENT OF THE NAVY SOLAR ENERGY ROLE

The U.S. Navy, like DOD and the entire Nation, is strongly dependent on conventional fossil fuels and consumes ever increasing quantities of these valuable resources. Supplies of petroleum and natural gas are limited, and the cost of these fuels is escalating at a dramatic rate. Hence, the cost of operating the Navy's ships, aircraft, transportation, and shore facilities is escalating at a comparable rate. This situation has motivated the Navy to establish an energy RD&D program, in support of DOD and national energy objectives. Its purpose is to seek methods for reduction in energy consumption and development of alternative energy sources capable of providing heating, cooling and power generation. The role of the Navy in participating in various DOD energy RD&D programs is summarized below. [Ref. 1].

1. Energy RD&D Effort.

The Navy's energy RD&D effort is researching old and/or new technology in order to achieve its three primary goals of conservation, synthetic fuel development and self sufficiency. These goals are briefly described below.

a. Conservation Program

(1) Reduce dependence on foreign energy supplies;

(2) Minimize impact of escalating oil and natural gas prices.

b. Synthetic Fuel Development

(1) Reduce dependence on foreign energy supplies;

(2) Alleviate vulnerability to fuel supply disruptions;

(3) Develop power systems capable of using synthetic fuels.

c. Self-Sufficiency Effort

(1) Reduce dependence on foreign oil supplies;

(2) Alleviate vulnerability to energy supply disruption;

(3) Develop power systems capable of using natural energy sources, coal and waste material; which includes alternative energy sources such as wind generation, geothermal sources, and solar energy.

2. Alternative Energy Source Search

As the cost of fossil fuels continues to rise, alternative sources of energy will begin to be more economically attractive. The Navy should, therefore, continue to look for advancements in technology and cost breakthroughs which can be applied to their own specific needs.

The Navy is also taking an active role in the development of local energy sources. For example, the Naval Ammunition Depot, Hawthorne, Nevada, has had two solar-heated homes in operation since November 1973. At the Naval Ordnance Laboratory, used helicopter blades have been used to investigate the possible use in wind machines with the output being used for resistance heating in buildings. The Naval Weapons Center at China Lake was to have recently begun work in exploring the Coso-geothermal area to determine if there was sufficient activity to warrant its development. The first solar energy water heating system in any Naval Medical Facility was being installed in the Summer of 1977 in the new Naval Medical/Dental Facility at Cecil Field, Florida. The system consists of solar collectors, water pumps and storage tanks. The clinic's existing heating system will serve as a backup. The Navy's Civil Engineering Laboratory (CEL), Port Hueneme, California, is developing various concepts and geometries for solar desalination of seawater into potable water, and is participating in a series of tests of various industry flat-plate solar collectors for the National Bureau of Standards (NBS). Data is computer processed to determine values of inlet/outlet temperatures, collector flow rate and ambient temperature versus the amount of available insulation. [Refs. 63, 64, 65, 109].

3. Energy Consumption and Operational Needs

During 1975, the Naval shore establishment consumed energy equivalent to 30 million barrels of oil. Of this amount, about 50%,

or 15 million barrels equivalent, were used by shore establishments for utilities for heating, ventilating and air conditioning (HVAC) purposes at an overall purchased cost of about $160 million. [Ref. 1]. It is estimated that between 20% and 35% were used directly for heating water. The potential for savings in HVAC use, in particular water heating, is significant, especially in light of President Carter's request to increase energy efficiency by 20% in existing buildings and 45% in new buildings by 1985. [Ref. 18]. Exhibit III provides statistics for various types of energy consumption in Navy and Marine Corps family housing for FY75.

Navy shore facility use of electricity in FY75 cost $165 million, or one-half of the total utility cost. While conservation efforts resulted in reduction of total energy consumption by 11.1% over the base amount used in FY73, electricity consumption was reduced by only 5.7%, which is a key reason why total Navy energy conservation fell short of the overall 15% reduction goal. The observation that many loads are being shifted to electricity as an alternative source, coupled with the current cost escalation guideline of 25% per year for electricity, clearly indicates the need for concentrated efforts toward electrical conservation and alternative energy sources. [Refs. 1, 16].

Utilizing waste material as a source of heat energy can make a major stride in conservation of conventional heating fuels throughout the naval shore establishment. If only 70% of the Navy's annual

generation of solid waste (25 million cubic yards) were converted to steam, a fuel oil savings of over 4 x 10^6 million (4,000,000,000,000) Btu per year would be realized. This represents about 7% of the Navy's total fuel oil consumption for FY75 at a cost of some $12 million. [Ref. 1].

The total cost of utilities for Navy shore facilities in FY75 was $321 million, and current guidelines indicate all energy costs will increase rapidly over the next few years. Significant savings in fuel consumption currently used for heating and cooling Navy buildings may be accomplished by the installation of solar energy systems where they can be shown to be cost effective. About 25% of the Navy's annual utility bill of $321 million (FY75) is spent for space heating and cooling and domestic water heating. This $80 million of the total annual Navy utility budget may someday be totally replaced by solar energy; however, in the near-term, only about 10% of the facilities could probably be economically supplied with solar energy through retrofitting techniques. Although the overall percentage is small, this area is at least a starting point for the Navy in its efforts to develop alternative energy sources in the future. [Ref. 1].

4. <u>Energy Management Plan</u>

Before viewing the Navy's current energy management plan and placing it in perspective with the overall DOD and National Energy Plan, it is necessary to look briefly at how the Navy is organized in

terms of energy RD&D support. The Naval Facilities Engineering Command (NAVFAC) provides energy engineering, material, and equipment support to the Chief of Naval Operations, the Operating Forces of the Navy, the Marine Corps, components of the Naval Material Command and other offices. NAVFAC's Energy RD&D Program is directed primarily towards items of new or improved materials, technology, and equipment or engineering techniques which will significantly help the Navy in its technical planning, design, construction, operation and maintenance of the shore establishment, which includes fixed surface and subsurface structures of the Navy. NAVFAC's Research Program is specifically administered by the Assistant Commander for Research and Development (Code 03). NAVFAC Code 03 has the responsibility to ensure that the output of RD&D efforts is transferred to shore activities of the Navy and to ensure that maximum effectiveness is achieved from RD&D investments. [Ref. 1].

a. Program Guidelines

The broad guidelines governing the content and operation of the Navy's shore establishment energy RD&D program are summarized in the following statements:

(1) The Department of Defense (DOD) has established that the development of many energy systems could be significantly accelerated by applications to military operations. The Energy Program Office instituted at CEL, NAVFAC Code 03, and the Navy Energy Office are integral parts of that effort.

(2) Although the total energy consumption by the Navy is a relatively small percentage of the national energy demand, the Navy is a large single consumer with a shore establishment annual utility bill of $321 million for FY75 and has an enormous shore facility replacement investment of $44 billion in terms of 1975 values. Consequently, large returns are possible from relatively small RD&D expenditures.

(3) Power systems and conservation technology developed under the national energy program and ready for transfer are either thoroughly analyzed, or the procedure to perform the analysis is made available by the Energy Program Office, in order to assure that economic and operational benefits can be expected before Navywide application is instituted.

(4) Some hardware research leading to the development of energy conservation and power systems is performed by the Energy Program Office when a concept with potential is unique to the Navy or has not been vigorously pursued by the national energy program.

b. Program Objectives

It is necessary for the Navy to develop and assimilate technology in energy conservation and power systems for applications at shore activities, optimized for performance, reliability, operating criteria, and economics, consistent with the national energy program. This technology base will provide the means for the Navy to achieve its primary goals of conservation, self-sufficiency of remote bases and forces, and utilization of synthetic fuels.

c. Management Plan

The Management Plan places the Navy shore establishment energy RD&D program in perspective with the DOD energy organization and the national energy program. The roles of contributing organizations in the execution of the program, documentation of

results and progress, and revisions to the program plan are set forth. These participants and how the program fits into the DOD energy organization are diagrammed in the DOD organization chart in Exhibit IV. Major contributions are also expected from Federal agencies outside DOD and the commercial sector as well. The functions of specific Navy activities are outlined briefly below. [Ref. 1].

(1) Civil Engineering Laboratory.

The Navy's Civil Engineering Laboratory (CEL), located at Port Hueneme, California, has as its mission "to be the principal Navy RDT&E (research, development, testing and evaluation) center for shore facilities, fixed surface and subsurface ocean facilities, and the Navy and Marine Corps construction forces." [Ref. 58]. The CEL's Energy Program Office is the focal point for the shore establishment energy RDT&E program, under the sponsorship of the Naval Facilities Engineering Command (NAVFAC). It provides the mechanism for building an energy technology base by assimilating advances made in the national energy program, and by conducting investigations at the Laboratory itself. The technology is then transferred to NAVFAC and its field activities. The structure of the Energy Program Office at CEL appears in Exhibit V, which also locates NAVFAC and other Navy facilities in the overall DOD organization.

(2) Naval Weapons Center.

The Naval Weapons Center (NWC), located at China Lake, California, is designated as the performing activity for geothermal development at naval installations, as an integrated technical goal in the shore establishment Energy Exploratory Development Program. The NWC provides for the documentation and presentation of results, recommendations, technical goal progress and status, handbooks and design criteria and program plans supplied to NAVFAC and field activities, and coordinates the conduct of the geothermal technical goal through the CEL. NWC also participates in formal NAVFAC program reviews of geothermal development.

(3) Naval Facilities Engineering Command.

The Naval Facilities Engineering Command (NAVFAC) Code 03 monitors progress of performing activities; e.g., CEL and NWC, in terms of meeting program objectives and technological goals within the allotted time frame and fiscal resources specified. In addition, NAVFAC Code 03 provides guidance for and approves the Block Program Plan for the Energy Exploratory Development Program for the Naval Shore Establishment, establishes funding levels and personnel billets at the CEL, maintains coordination with various DOD organizations and Federal agencies in various energy programs and other matters.

(4) Navy Energy and Natural Resources R&D Office.

The Navy Energy and Natural Resources R&D Office (NEO), located in the offices of the Chief of Naval Material, Code MAT 03Z, serves as the Chief of Naval Operations, Chief of Naval Material, and Chief of Naval Development designated point of contact for all energy technology programs within the Navy.

(5) Navy's Energy Hot Line.

The CEL provides as part of their existing telephone "hot-line" answers to energy questions on a 24-hour a day basis by calling AUTOVON 360-4070, or Commercial (805) 982-4070. [Ref. 60].

(6) Advanced Energy Utilization Test Bed.

As part of the Navy's overall energy program, the CEL operates a test project called the Advanced Energy Utilization Test Bed (AEUTB). This project is centered in a test structure containing 1,300 square feet of working space. By altering the thermal characteristics of the building shell itself, it can be used to simulate such typical facilities as offices, medical facilities, or residential structures complete with functioning heating, ventilating, cooling and sanitary systems. Currently it is being adapted to test various solar energy systems for development and demonstration purposes. The AEUTB program is under the direction of the CEL's Energy Program Office. Technology developed during the program will be made available to the Navy, and through the Navy's Technology Transfer

Program, to other government agencies and to the public. The AEUTB will be available for research purposes, on a non-interference basis, by any Government agency. [Ref. 59].

For further information contact:

Dr. Lawrence W. Hallanger
Code L03AE
Civil Engineering Laboratory
Naval Construction Battalion Center
Port Hueneme, California 93043.

5. Energy Engineering Program (EEP)

In cooperation with NAVFAC and the Navy Environmental Support Office (NESO), the CEL has started an Energy Engineering Program (EEP) as specified in the Navy Energy Plan. The plan calls for a study of energy conservation in industrial activities within the Navy such as shipyards and Naval Air Re-Work Facilities, as well as government-owned, contractor-operated plants. In addition, an air conditioning tune-up program is planned to improve efficiencies of large air conditioning plants.

NESO will prepare work statements for contracts which will be reviewed by NAVFAC and the CEL. Contracts then will be let through designated Engineering Field Divisions (EFDs) of NAVFAC, fulfilling the objectives of the EEP. This current fiscal year (FY78) the CEL is supporting the initial EEP through the engineering development phase, and the program will make a transition to an operational mode in FY79.

Presently, CEL and NESO are conducting statistical studies to support the establishment of a computerized energy data file. It will include energy consumption data at Naval facilities and energy availability in terms of solar, wind and other alternative energy sources. [Ref. 99]. Questions concerning this program as well as other CEL energy matters should be directed to:

Mr. Fred Herrmann
Code L03C
Civil Engineering Laboratory
Naval Construction Battalion Center
Port Hueneme, California 93043
Autovon: 360-5562
Commercial: (805) 982-5562.

VII. RETROFITTING SYSTEM CHARACTERISTICS

A. DEFINITION OF RETROFIT

A "retrofit" project involves the installation of solar energy equipment in an existing building, residence or other similar facility. This Chapter will discuss possible retrofitting techniques that could be used by the U. S. Navy in converting its existing facilities for use of solar energy systems.

B. NAVY FACILITY PERSPECTIVE

> The physical architecture of the new society will require the utilization of sophisticated technologies of the present to bridge the gap of history to the styles of the past, when climate reigned supreme.
> [Wilson Clark, Energy for Survival, Ref. 26].

The aforementioned quote seems to have more relevance when one considers that most of the Navy's solar homes of the future have already been built today. In fact, the inventory of existing adequate housing units maintained by the Navy totals about 82,171 units. [Ref. 40]. Therefore, when viewing the Navy's housing assets for consideration of solar energy, the most promising market for the short-term rapid development of solar energy systems lies in retrofitting the existing housing units that have already been constructed.

As of 1975, the Navy's housing assets fell into four broad categories:

Before 1950	10,525
Wherry	15,019
Capehart	21,184
1950 and After	35,443
Total:	82,171

For all practical purposes, however, the 10,525 units listed in the Before 1950 category would not qualify for retrofitting and could be dropped from consideration for the following reasons: (1) median age is over 40-years old; (2) little repetition of building type; (3) non-criteria unit size and configuration; and (4) occupancy and historical considerations. The revised total would then be 71,646 units.

New construction and housing already in the pipeline since the date of the latest inventory report project than an additional 8,152 units will be placed in use within the next ten-year period. [Ref. 40]. Therefore, the complete revised total would be approximately:

Existing housing units	71,646
Projected new construction	8,152
Total available:	79,798

For planning purposes, this figure can be rounded off to 80,000 units. This is what the Navy will have in the way of housing units to work with over the next ten-year period. Retrofitting applications can be considered for 71,646 units while new solar system designs can be considered for the remaining 8,152 units. This represents a sizeable market potential

for the Navy to demonstrate the practical application of solar energy systems in support of the national solar energy RD&D program. Commitment, a strong solar energy program, and top management involvement are critical in realizing the potential savings available through solar energy system installation.

C. IDENTIFYING RETROFIT CANDIDATES

There are numerous architectural, engineering, contractor and government manuals available on the market today that include building retrofit projects that will save energy and resultant costs. Some identify energy conservation and some identify alternative energy sources to save energy. One of these manuals is Identifying Retrofit Projects for Buildings, issued by the Federal Energy Administration, dated September 1976. The particular method illustrated in this manual is designed to build on the success of prior applications by relating the appropriate and proven projects to specific energy use systems that can be easily identified in a given building or residence. [Ref. 68].

A schematic overview of the suggested method to be employed for an individual application is shown in Exhibit VI. A brief description of the various retrofit procedural steps is given below.

1. Step 1 - Collecting Energy Use Data.

This step provides fuel cost data necessary to calculate cost savings in a later step, and also provides an overall sense of priority

for retrofitting projects. Fuel forms that account for the largest part of the total fuel bill should receive greatest emphasis in planning retrofit projects.

2. <u>Step 2 - Categorizing Buildings</u>.

In this step, all of the buildings at a facility are ranked in terms of size, and thus by their probable proportion of energy use; buildings are categorized into types; and the climate zone that corresponds to a facility's location is identified.

3. <u>Step 3 - Identifying Retrofit Options</u>.

In this step, reference tables link appropriate candidate retrofit options with specific energy systems as a function of building type and the climate zone in which the building is located. In addition, retrofit projects already planned can be easily incorporated.

4. <u>Step 4 - Evaluating and Ranking Projects</u>.

In this step, the energy and cost savings of individual retrofit projects are calculated, along with their associated investment costs. The options are then ranked in terms of the time it would take for them to pay back their investment cost.

Further detailed methods for identifying retrofit projects including examples and various tables and charts is described in the aforementioned manual -- <u>Identifying Retrofit Projects for Buildings</u>. Additionally, evaluation and ranking of the retrofit options is described along with how to determine the simple payback period (SPP) -- the total capital cost

of the retrofit project divided by the net dollar savings per year. Once all the options for an entire facility or residence have been examined, the date can be entered onto a form for comparison basis, and placement of a priority based on the SPP.

D. RETROFIT PLANNING AND DESIGN CONSIDERATIONS

1. Retrofit for Energy Conservation First

In many studies and actual project evaluation, decreased energy use is attributed to effective energy conservation "retrofitting" of existing commercial/industrial and residential facilities, including use of additional insulation, thermopane windows, reduced levels of heating and cooling, and installation of automatic controls and equipment monitoring. The status of DOD energy savings as of February 1977 is shown in Table VI.

Retrofit projects of the type mentioned in the previous paragraph have a high return on investment, both in terms of energy and dollars. Additionally, projects concerning the height of ceilings are common in many Government projects. The fact that some Navy facilities have ceilings ranging from 10 to 16 feet in height creates problems in lighting and space conditioning (heating and cooling). These facilities are heating and cooling this unused volume of air and wasting the excess energy required for high light fixtures. Careful consideration should be given to lowering the height of such facilities.

Table VI. Status of Government Utility Consumption
(As of February 1977 - Source: Ref. 4)

DEPT/AGENCY	FY 73* BASE ($Btu \times 10^9$)	FY 76** ACTUAL ($Btu \times 10^9$)	% RED.
1. GSA	61,157	43,956	28
2. NASA	32,859	24,331	26
3. LABOR	1,732	1,337	23
4. DEFENSE	552,717	469,094	15
5. COMMERCE	2,888	2,452	15
6. TREASURY	2,005	1,754	13
7. HEW	8,048	7,045	12
8. ERDA	95,332	83,826	12
9. JUSTICE	5,209	4,951	5
10. TRANSPORTATION	15,719	15,770	0
Total:	777,666	645,516	15.8

*FEA, FEMP FY 1974, First Annual Report, December 1974
**FEA, FY 1976, Energy Conservation Performance by Agency/ Department

During 1972 and 1973 a variety of studies began which estimated the amount by which energy demand could be reduced if buildings were designed and constructed or modified to be energy efficient. The estimates varied considerably as a function of the varius components each study considered and with differing judgements of technical and economic feasibility. The estimates ranged from 10% to 50% for

retrofitted buildings. At the time, it was concluded that 30% was a reasonable average of conservation potential for the retrofitted building. Further information on these studies which includes evaluating the capital issues of a national program for energy efficient buildings, capital supply and demand charts, summary of the entire analysis and many recommendations is included in two brochures issued by the American Institute of Architects, titled A Nation of Energy Efficient Buildings by 1990 and Energy and the Built Environment: A Gap in Current Strategies. Both of these studies can be obtained at a nominal charge from:

The American Institute of Architects
1735 New York Avenue, N.W.
Washington, D.C. 20006

2. Practical Applications in Retrofit Construction

a. Step 1 - Investigate Alternatives

In the initial planning and design stages of any solar energy system, there are a number of alternatives that impact on the overall system design. Among these alternatives are: (1) the type of space heating/cooling or water-heating system to be used; (2) the type of solar collector to be used; (3) the location of the collector -- tilt angle, roof mounted or ground array; and (4) the type of thermal storage tank to be used and its location. A key factor in selecting an alternative is the nature of the solar energy system application. For example, the application will either be designed

into new construction or retrofitted into an existing facility. The differences between the two are significant. The retrofitting type will be discussed in this Chapter and the new-construction type will be discussed in Chapter VIII.

b. Step 2 - Determine Availability of Equipment

Anyone contemplating installing a solar system in an existing building (commercial or residential) must first investigate what solar equipment is available to him and whether it is right for the particular locality and purpose. It must be remembered that installing a solar system in an existing building -- retrofitting -- is a different matter from installing one in a new building. For one thing, there is considerably less information to go by on the retrofitting application. Studies completed for the Federal government have been somewhat pessimistic about the practicality of retrofitting, but research and development is continuing.

c. Step 3 - Select Experienced Contractor

In the planning stages it is necessary to seek a contractor who has experience in the field of solar energy -- and its also a good idea to hire an experienced architect or engineer to check the contractor's claims. One of the primary things to check is the solar collector efficiency and reliability. The CEL and other Government agencies have information and/or are developing information on various solar contractor submitted claims on solar collectors.

In selecting the contractor/solar manufacturer, be careful of the literature and analysis provided for review. The decision maker would do well to consider whether or not the proposal is prepared by, or influenced by, a person who advocates it. Any advocacy proposal is essentially a document that is designed to sell the proposal to the decision maker. Most proposals submitted on solar energy systems can probably be said to be advocacy proposals; indeed, if the manager/contractor is not an enthusiastic supporter of the proposal, there is probably something wrong with the proposal.

Another point to consider in reviewing a contractor/manufacturers literature or proposal on solar energy systems is that it may be biased in any one of the following ways:

(1) Consequences are asserted without adequate substantiation through RD&D efforts or "proof-of-concept."

(2) Technical system matters beyond the comprehension of the decision maker are discussed at length -- the "snow job." Remember, most solar space heating/cooling and water heating systems are fairly simple to assemble.

(3) Opposing views are omitted or not faithfully reported. One approach to take if this occurs is to establish an advocacy relationship. For every important proposal, there is some group that opposes it. Arrangements might be made to seek opposing arguments through debate, point papers, or alternate proposals whereby the merits and weaknesses of the proposal can often be illuminated.

(4) The manufacturer's/contractor's proposals should describe what is to be done, but ordinarily do not contain the details of how it is to be done. These details are the responsibility of the operating management, to be worked out after the proposal has been approved or included in the contract specifications.

d. Step 4 - Determine Most Practical Solution

Essential changes, such as roof reconstruction or modification, may not be practical from an economics standpoint. For example, an existing roof may have to be structurally stiffened to support the extra loading imposed by the solar collectors. In addition, the pitch of the roof may have to be altered significantly in order to achieve the necessary sun angle (typically dependent on the geographical latitude of the location). In new construction, however, these difficulties can be incorporated into the overall design and site location -- this can't be accomplished easily in an existing building. For these reasons, it may be more practical to consider a ground-mounted solar collector array in retrofitting situations.

e. Step 5 - Select Storage Tank Type and Location

The next consideration in planning for the solar system is the location of the storage tank. Choices for the storage medium include water, crushed rock or eutectic salts.* In the retrofit situation

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*Eutectic salts appear to have promise for the future but for the present time further RD&D efforts are necessary for a positive proof-of-concept and to reduce maintenance problems. Whereas water and

this presents a serious space problem. Consider the problems involved in locating a huge water-storage tank or 15-20 tons of crushed rock near the mechanical room, normally the size of a large closet in many cases. The expense of tearing up the floors and excavating costs must be considered. In most Navy family housing units, especially in townhouses and apartment-type units, space is already at a premium. Any further reduction in floor space would be self-defeating (for morale of the occupants) in spite of the potential savings. Therefore, it may be that the storage tank would be limited to a buried water storage tank adjacent to the housing unit or commercial facility. However, in the case of merely satisfying solar water-heating criteria, a solar water storage tank -- similar to the conventional water heater, except without the heating coil -- may suffice. This is normally an 80 - 120 gallon storage tank that can be located adjacent to the existing conventional water heater, or in close proximity to the existing water heater. In some cases, however, a completely separated location is required.

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crushed rock store thermal energy collected as sensible heat, eutectic salts store it as latent heat. Eutectic salts release stored thermal energy by undergoing a phase change. The thermal energy is stored in their molecular structure -- in a liquid phase. Subsequently, when it is necessary to recover this stored energy, a phase change is induced, whereby the eutectic salts enter the solid phase giving up their stored energy.

f. Step 6 - Select Solar Collector

The collector is the most important -- and most expensive -- part of the solar system. It must be long-lived and well insulated. In retrofit applications, the self-contained or modular type of collector must be used. This is because it is normally mounted on top of the roof rather than integrated in the roof structure as in new construction. The modular type of collector is normally more expensive than the other type because it must have backing insulation or surfacing and be mounted on brackets keeping it detached from the roof

Collectors of primary interest for space and water heating are of two basic types: liquid and air. Liquids may be water, "heat-transfer" oil, or antifreeze mixtures. Heat collector plates are commonly made of copper, aluminum or galvanized steel for liquids, and the same materials plus all-glass for air systems. Copper and all-glass collectors are currently the only types having reported lifetimes greater than five years. Collectors using water in copper tubes are reported to last over 20 years and in air-in-glass collectors, indefinitely. Tubes should be greater than 1/2-inch in diameter for longer life and lower pressure drop. [Ref. 36]. For an explanation of the air- and liquid-type systems refer to Section G, Chapter III.

There are three basic types of solar collectors: the flat plate collector, the tracking or concentrating collector, and the evacuated tubular collector. Figure 4, in Chapter II, illustrates these three types of collectors.

g. Step 7 - Feasibility of Solar Water Heater

If you are trying to retrofit a large townhouse or apartment complex, check to see if the central boiler, if one is used, supplies hot water or if there is a separate unit just for hot water. If it is from a central boiler system, the boiler operating personnel in the Utilities Division will know whether the system is operating below 20% of capacity during the warmer months of the year. If so, then, as a rule, the amount of fuel used to generate that hot water could be cut by 50% through the installation of a smaller (or several smaller), more efficient unit(s) just for hot water. The small, individual solar water heater might be just the answer for this situation. Since the savings from installing a decentralized water heater depends on the number of people being served by the system, determine the occupancy of the complex served by the central system.

In planning for the solar water heater, remember that although 100% solar heat is technologically possible, it is usually not economically practical because it necessitates a prohibitively costly investment -- especially in solar collector and storage tank size. In most cases, it is advantageous to have an auxiliary water heating system, the standard conventional water heater.

h. Step 8 - Consider Other Possible Modifications

Typical dwelling modifications that might be considered are evidenced in the 877 units of family housing located at the Naval Postgraduate School, Monterey, California. Of these units, a total of 759 have individual hot-water heaters (HWH) and the balance have multi-unit type common hot-water heaters -- e.g., central units. Of the 729 single- or duplex-type units with separate water heaters, there are a total of 29 different house plans, each requiring a different design. Eighteen (18) of these plans require little or no structural modifications to install the solar equipment (except for perhaps minor roof-truss strengthening and flashing, etc.). All plans require installation of the extra solar storage tank, pump, valves, and associated plumbing system. Several plans require moderately lengthy insulated pipe runs between the new solar tank and the existing conventional HWH tank. Eleven (11) plans require significant modifications which consist typically of three types:

(1) an extension of the existing exterior utility closet space containing the existing HWH to make room for the solar tank;

(2) the construction of a small exterior storage shed enclosure for the solar storage tank; or,

(3) the installation of the solar storage tank in an existing interior hall or kitchen closet with the attendant requirement to build a replacement storage closet. Existing storage space in most dwellings is quite limited.

Additionally, due to the site orientation of many housing units, it would be necessary to install "roof racks" to reorientate the solar collectors to the direction of the maximum sun exposure, which would require major structural modifications to the roofs, or the installation of ground-mounted arrays for the collectors necessitating long piping runs from the collectors to the storage tanks in the house -- additional expense and loss of system efficiency can be expected here.

E. RETROFIT STUDIES FOR REVIEW CONSIDERATIONS

Additional information on solar retrofitting of housing is available through two studies recently performed by the U.S. Air Force. The first is a technical report titled Solar Heating Retrofit of Military Family Housing which was released in September 1976. It provides an initial accounting and performance rating of a retrofitting project conducted at the Air Force Academy. Two adjacent identical housing units were involved in the study which is still being monitored by the Air Force. One unit (of the duplex) was outfitted with solar heating, including a computerized monitoring and control system; the other, was hooked to the same computer for monitoring, but no other modifications were made. Numerous changes were made during the first year to the solar-heated home, however, to improve insulation and otherwise increase the energy conservation of the unit. The result, according to Colonel Wallace Fluhr, professor and head of the

academy's civil engineering department, is that they have "... achieved a 50% reduction in the use of natural gas for heat during the winter and a 100% reduction during the warmer months." [Refs. 54, 72].

The second study, also conducted by the Air Force, titled Solar Assisted Heat Pump Study for Heating and/or Cooling of Military Facilities, began in July 1976. Two of the three phases of this study were completed in May 1977. Phase III continues the study. The project officer for this study is: Mr. Fred Beason, Code CEEDA/CNF, Tyndall AFB, Florida 32403, AUTOVON No. 970-4212. [Ref. 73].

VIII. NEW SOLAR SYSTEM CHARACTERISTICS

> In 25 years, the world we live in will not be recognizable. Petroleum will be well on its way out. New houses won't look anything like they do now. Patterns of living will have shifted in ways that are difficult to predict now ...
> (Solar Age magazine) [Ref. 82].

A. GENERAL

This Chapter will discuss techniques for designing and building solar systems into new Navy facilities yet to be constructed. In order to decide which type of solar energy system is best for the particular situation, it is necessary to look at the various types that are available on the market today. In addition to the illustrations shown in Section G, Chapter III, a more detailed summary of solar system characteristics is presented in Exhibit VII. Hopefully, these characteristics can be matched with the problem faced in deciding on the type of system needed. This particular summary is taken from Designing and Building a Solar House, by Donald Watson, AIA, member of the architectural faculty at Yale University. He has been involved as designer or consultant in over 80 different solar heating projects, has written several articles for the American Institute of Architects (AIA) Research Corporation, and authored three books on the subject of solar energy.

Solar engineering is one part of house design which aims at reduced energy costs, but the most cost effective, fuel saving measures start with the planning of the house (or other type of building) itself, including site planning, window location, interior zoning of the rooms, wall insulation and other features that reduce energy requirements.

Many techniques of solar heating can be incorporated into the house construction: solar-oriented windows, masonry used as heat storage, and greenhouse attachments used as intermediary zones. In parts of the United States, such passive solar heating devices are all that are required to heat a home. ... Some methods are particularly suited to custom-built houses, others to the built-for-sale house, depending on financing and construction method considerations. (Donald Watson) [Ref. 74].

B. PLANNING

Basically, any approach to solar system design should start with efficient planning to reduce fossil fuel energy consumption requirements and consider the appropriate use of construction for solar heating, cooling, or water heating systems. Systems may be either active or passive, although in new construction the passive system offers what many leading solar energy designers and manufacturers consider to be the most cost-effective system. "The last step should be the selection of the solar mechanical system that is required. In this way, what might otherwise be a large investment in solar equipment can be made reasonable and practical in size and cost." [Ref. 74]. Additionally, as fossil fuel costs increase, large capacity solar space heating and cooling and water-heating systems become more cost justified, to the extent that the residence

or commercial building of the future will definitely use some alternative source of energy to supply the majority of its energy needs.

C. SYSTEM CHARACTERISTICS

Several characteristic properties apply to all solar space heating and cooling and water-heating systems, whether they are simple or relatively complex, or whether they are small individual units or large multi-unit systems. Basically, any solar system consists of three generic components: (1) the collector; (2) the storage medium; and (3) the distribution system. These components and their characteristics were discussed previously in Chapter III and therefore the specific details need not be repeated here.

These components may vary widely in design and controls. They may be one and the same element, e.g., a masonry exterior wall can be a collector, although a relatively ineffective one, which stores the sun's heat directly in the building skin and radiates or "distributes" heat directly to the building interior. This is the "passive" concept. Or, the system may use separate collectors to heat up some fluid or air to transfer heat to a storage tank. This is the "active" concept. They may also be arranged in numerous combinations dependent on function, component compatibility, climatic condition, performance, and/or architectural design concept and aesthetic value. In fact, Donald Watson's solar heating designs and system alternatives

summary (Exhibit VII) conveys an important message: "that a combination of active and passive systems is often the most viable choice for house design ...". [Ref. 74].

Additional detailed descriptions of the various solar energy system components, characteristics, types of collectors, storage medium and distribution component interface characteristics is given in Solar Dwelling Design Concepts, by the AIA Research Corporation for the U.S. Department of Housing and Urban Development, May 1976. [Ref. 75]. Therefore, for further information on system characteristics you are referred to this particular source, which may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price $2.30.

D. FIVE BASIC SOLAR DESIGN PRINCIPLES

For new construction, simple design considerations for solar energy utilization can heat and cool most buildings quite effectively and at minimum cost. There are five basic solar design principles that should be incorporated into all new buildings wherever practical. It has been estimated that these five basic principles could conserve up to 50% of the total heating and cooling costs. [Refs. 68, 77].

1. Insulate and Weatherstrip the Building.

Various State building codes and Laws differ in the minimum requirements for insulating new construction. It is therefore best to

check your local building codes and Laws applicable to insulation. Energy used for heating and cooling can be saved by caulking around windows and openings, and installing weatherstripping around doors that open to the outside. Additional roof insulation is a good idea -- installing an additional 3 inches (or equivalent) of fibrous insulation can save 10% of the energy used. Double glazing can reduce the heat loss through windows by 50%.

2. Orient the Long Axis of the Building So It Faces South.

This orientation takes advantage of the sun's south exposure.

3. Place Most of the Windows on the South Side.

This allows window exposure to the sunlight for heat gain during the winter months when the sun is low on the horizon.

4. Provide an Overhang on South Glass for Summer Shading.

This blocks out the high summer sun yet permits entrance of the winter sun.

5. Cover the Roof with a Light Color Surface Material.

E. ARCHITECTURAL/DESIGN CONSIDERATIONS

NAVFAC Technical Report No. R-835, Solar Heating Buildings and Domestic Hot Water, suggests that solar design should be studied to facilitate blending the collector panels -- since these are normally all that appears exterior to the house -- into the architecture of the new (or existing) building or residence. Shade trees and bushes on

the site must be located so as not to cast shadows on the collector -- if they are being planned for in the new facility's surroundings -- or the building itself must be oriented on the site so that the existing trees and shrubs that remain do not screen the sunlight from the collectors. It is for these critical reasons that many State and Local governments are implementing "right to light" Laws to protect the solar user from light intrusion by others -- i.e., condemnation procedures, etc. Other structures, such as chimneys, etc., that jut up above the roof, and cast shadows, should be carefully located to avoid shading of the collector.

Experience of various Florida solar energy system installers indicates that if the collectors are placed directly on the roof, the life of the asphalt shingles directly under the collector may be reduced by as much as 50% -- this should be especially critical in retrofit installations applied directly on the existing roof. This problem suggests that a small space should be left between the collector and the roof by mounting the collector on some type of roof rack, or the collector should be built into the roof with normal flashing, insulation, etc., forming an integral part of the roof. In the latter case, design must provide for simple glass or plastic cover replacement and/or any minor maintenance that may need to be performed. Situations that have apparently occurred in deterioration of the roof shingles under the solar collectors may make the application of ground-mounted

solar collectors more practical, not only for economics and roof protection, but also from a maintenance and/or repair standpoint. After all, the ground-mounted collector array is much easier to reach.

Often the success or failure of a solar system depends upon the degree to which the solar components can be integrated into the entire domestic scene, as in the case of residential applications. The problem is mainly engineering, but it is also one of architecture which is particularly important in blending in the system with the design of the home. This is especially true in retrofitting situations which concerns the bulk of the Navy's assets, both industrial and residential. However, the Navy still will be building facilities in the future, so each facility should be designed with an alternative fuel source capability taken into consideration. Whether or not it makes sense economically to design in the solar energy system depends mainly on the architectural solution. In a typical building of the current cheap-energy era, a solar system is almost always too costly when competing with fossil fuel sources other than electricity. However, if the building is designed (or remodeled) to make use of the sun and wind, then it may pay to include a solar energy system in the design now. The building itself could become a "passive" solar system.

F. DIRECT (OR PASSIVE) SOLAR FOR HEATING AND COOLING

The best approach for heating and cooling buildings is to do it as simply and as economically as possible, and to use existing building materials and technology. Direct or passive solar utilizes this approach. Buildings designed to accept or reject heat directly do so without the need for expensive solar equipment and hardware systems. The energy storage and transfer system is often the building skin itself. It collects and radiates the energy throughout the building naturally.

Many primitive civilizations practiced direct solar design of their dwellings hundreds and thousands of years ago. The Indians of Mesa Verde, New Mexico, constructed their dwellings utilizing the principles of direct solar heating and cooling as early as 1200 A.D. To this day they are still heated and cooled naturally because they respond to the physical properties of nature. During the winter, when the sun is low in the sky, the warming rays of the sun can enter and heat the dwellings. During the summer, when the sun is high in the sky, sunlight cannot enter the interior of the dwellings because of the dwelling's design configuration, thus keeping them cool. See Figure 14 for an illustration of how this principle works.

Beginning with the five basic solar design principles, outlined in Section D of this Chapter, modern buildings and residences can take advantage of the local micro-climate in order to let nature do

the work of keeping the buildings comfortable the year round. The next step is to increase the thermal mass which results in an increase in the heating and cooling potential of the building. This can be

MESA VERDE (ca. 1200 AD)

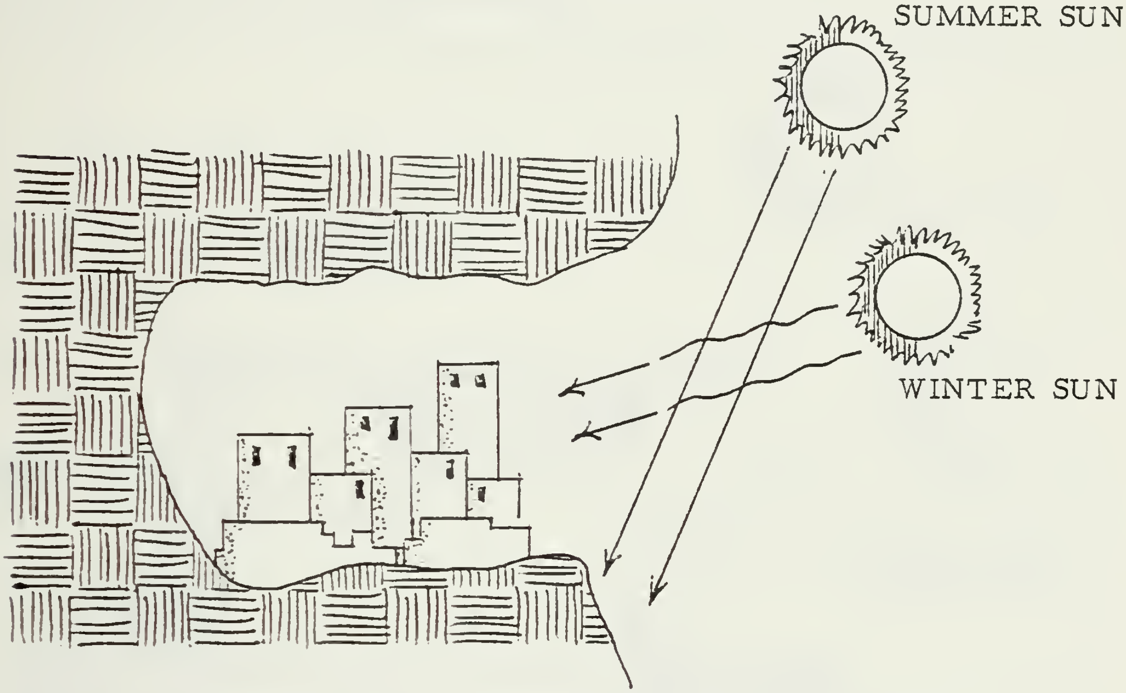


Fig. 14. Typical Mesa Verde Natural Solar System. (Source: Ref. 37).

accomplished by using dense materials inside the building, such as concrete, masonry, adobe, rocks or water. Some people have used 55-gallon drum barrels or beer cans, painted black for its thermal qualities, and filled with water to absorb and store the sun's heat. These materials are used because they have a high capacity for storing heat. For heating, the south window(s) should be designed in a manner to allow the sun's rays to enter the structure and directly heat the mass.

The mass will subsequently radiate the heat back into the living spaces. The heat can be retained for long periods with movable window insulation. Auxiliary heat from a conventional heating system provides backup for periods of extended cloudiness. See Figure 15 for an illustration of modern design.

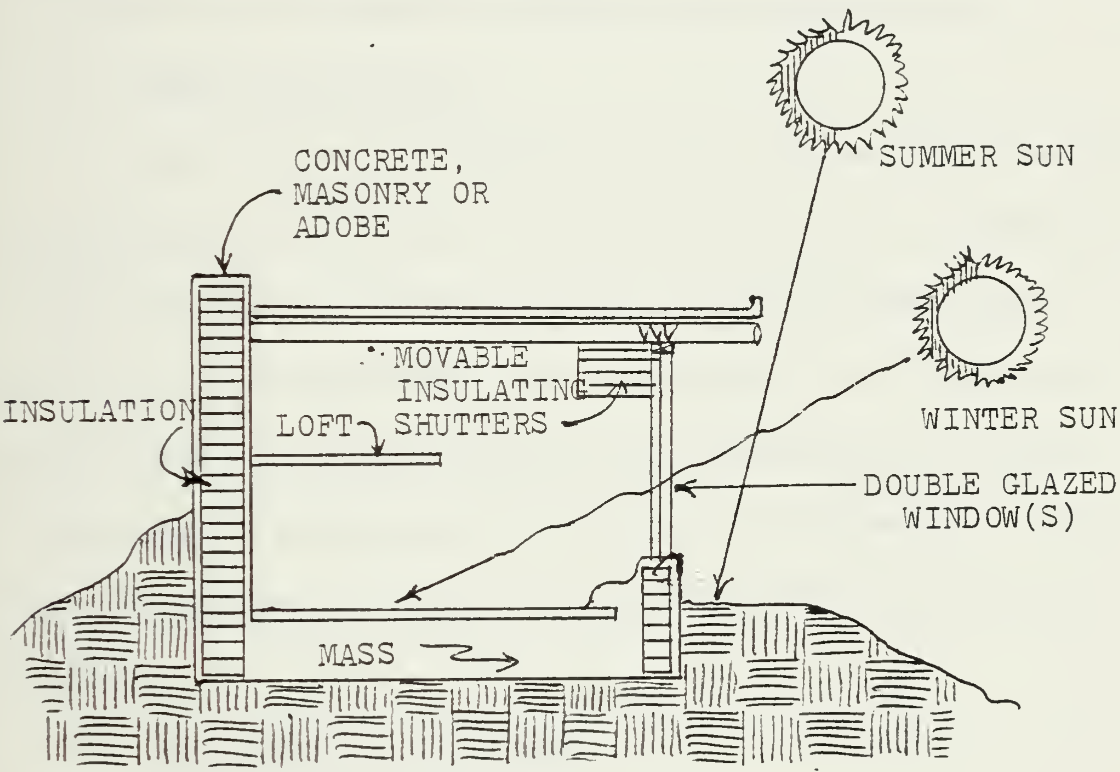


Fig. 15. Modern Use of Direct (Passive) Solar Energy. (Source: Ref. 37).

G. PRACTICAL APPLICATIONS IN NEW CONSTRUCTION (SUMMARY)

1. Direct (or Passive) Solar.

Direct solar is the most cost effective method of heating and cooling. The buildings are designed so they accept or reject heat directly.

2. Solar Water Heating.

Solar water heating is practical for new buildings and homes in most areas of the country. Payback time is approximately 10 years. [Ref. 77]. Considering that these systems may last 20 or more years, solar water heating is probably the most economically attractive use of solar systems available to the Navy at the present time.

3. Solar Pool Heating.

Solar heating for swimming pools is less expensive than any other method of pool heating over the life of the pool. In most cases a solar pool heater will pay for itself within five to seven years. [Ref. 77]. In the near future, solar energy may be the only alternative left for heating swimming pools. Several states, including California, are considering strict measures of regulating pool heating in the near future -- e.g., cutting off supplies of natural gas. [Ref. 80].

4. Indirect (or Active) Solar.

Presently, most solar space heating systems are of the indirect (or active) type. Indirect solar is a solar heating or cooling system in which the solar heat is collected outside of the building by collectors and transferred to the inside through ducts or pipes, with fans or pumps. Recent developments in the solar energy field demonstrate that indirect solar will be most practical when retrofitted to existing homes or buildings and in other specific situations where direct solar cannot be accomplished.

5. <u>Solar Assisted Heat Pumps.</u>

Solar assisted heat pumps provide a cost effective application of solar energy in many cases. They warrant further investigation for heating and cooling of buildings but have potential for the future. The U.S. Air Force is currently working on a detailed study of solar assisted heat pumps. Many solar assisted heat pump systems have been researched and evaluated and six have been tentatively chosen for further consideration. A full discussion of the twenty-one systems and methods of analysis is included in the report, as well as the six under further consideration. These six tentative system selections are:

a. Air collector, rock storage, unitary or split heat pump of any generic type, solar energy used for direct heating only.

b. Identical to system a. but employing a liquid collector and water storage.

c. Centralized liquid collector and water storage, incremental water/air heat pumps connected to a common hydronic loop.

d. Liquid collector, water storage, unitary water/air heat pump.

e. Air collector, rock storage, unitary air/air heat pump.

f. Identical to system a. but employing a split air/air heat pump.

Because each application must meet unique conditions for a given house, geographical location and climate, any one system cannot be

selected as best for all conditions. In some cases, systems not included in the six tentative selections may prove more desirable and the choice should be left open. [Refs. 78, 79].

In addition, the U.S. Navy has completed a similar study titled Defense Energy Initiatives Ten-Year Solar Program for Naval Shore Establishment Housing Units, 15 January 1977, which also looks at the solar assisted optimized heat pump (SAOHP) system. The plan proposes a combination of flat plate collectors, water-to-water heat pump transfer and buried water storage/back-up system. The solar equipment configurations proposed in the study are considered to be the most economical possible utilizing available off-the-shelf technology. The Navy's study includes an inventory of the equipment needed, performance criteria, cost analysis, and industrial support required. The preliminary economic study indicates that the proposed retrofit solar systems are currently economically attractive in all zones where electricity is the source of heating, water heating and air conditioning (must be reviewed to confirm these conclusions on a case-by-case basis depending on specific geographical location) and that solar water heating appears economical in air conditioning zones even where natural gas is used. [Ref. 40].

6. Indirect (or Active) Solar Air Conditioning.

Indirect (active) solar for air conditioning is currently not cost effective for single family residences or small commercial buildings. It may achieve cost effectiveness for large (primarily

commercial/industrial) applications. Additional RD&D efforts are required to make this application more economical.

7. Solar Cells.

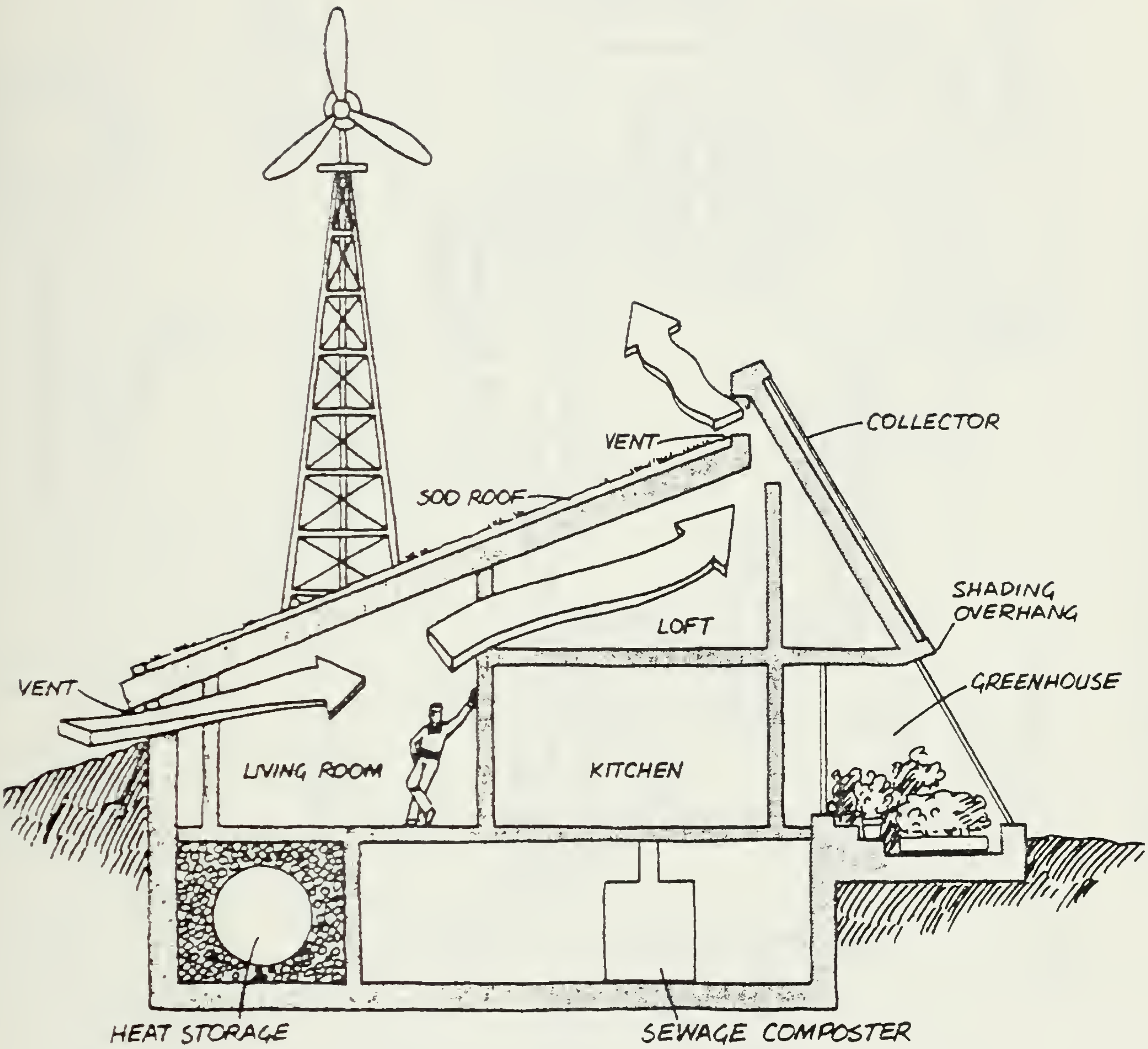
All of the above solar energy uses are for heating and cooling applications. Solar cells are used for photovoltaic electricity generation. (See Chapter IV for additional information). They are not expected to be practical for home utilization in the near future except for very remote and specific applications, e.g., to run attic fans, etc. At the present time their cost is too high for more practical uses.

H. TOTAL ENERGY CONCEPT OF THE FUTURE

The solar energy home of the future will be one that is designed from the ground up to take full advantage of all the natural common amenities that are available. The home will take into consideration the wind, solar energy, back-up systems, the "greenhouse" effect, underground heat storage, solar cells for power generation, sewage composter for bioconversion of waste products, and an aesthetically pleasing blend of new architecture combined with natural solar energy effect concepts known to mankind for over 2,000 years. Bruce Anderson, Architect, executive director of Solar Age magazine and a director of the American section of the International Solar Energy Society, and author of several books on solar energy, has described such a home.

> Autonomous living is the theme of an experimental house built in Rosemount near the University of Minnesota. Called Ouroboros after a mythical dragon that survived by eating its tail and regenerating itself, the house began as a design project .... A total of 160 students contributed designs and labor toward making the house a reality. It has been occupied since June of 1975 by a student and his family. An evolving laboratory for energy conservation and self-sufficiency, Ouroboros already has such "novel" features as a sod roof, a windmill, and a composting toilet ... The entire project cost $95,000 and was funded entirely from local sources ...
> (Bruce Anderson) [Ref. 26].

A schematic design of Ouroboros is illustrated in Figure 16. Note the simplicity of design and utilization of many practical applications of nature's energy sources. With a little imagination and the dreams of tinkerers and scientists alike, this autonomous living could become the theme for all Navy housing in the future. Figure 17 schematically illustrates how a total solar energy might look in future residential applications.



Ouroboros – a model house for energy conservation and self-sufficiency.

Fig. 16. Ouroboros - A Model House of the Future? (Ref. 26).

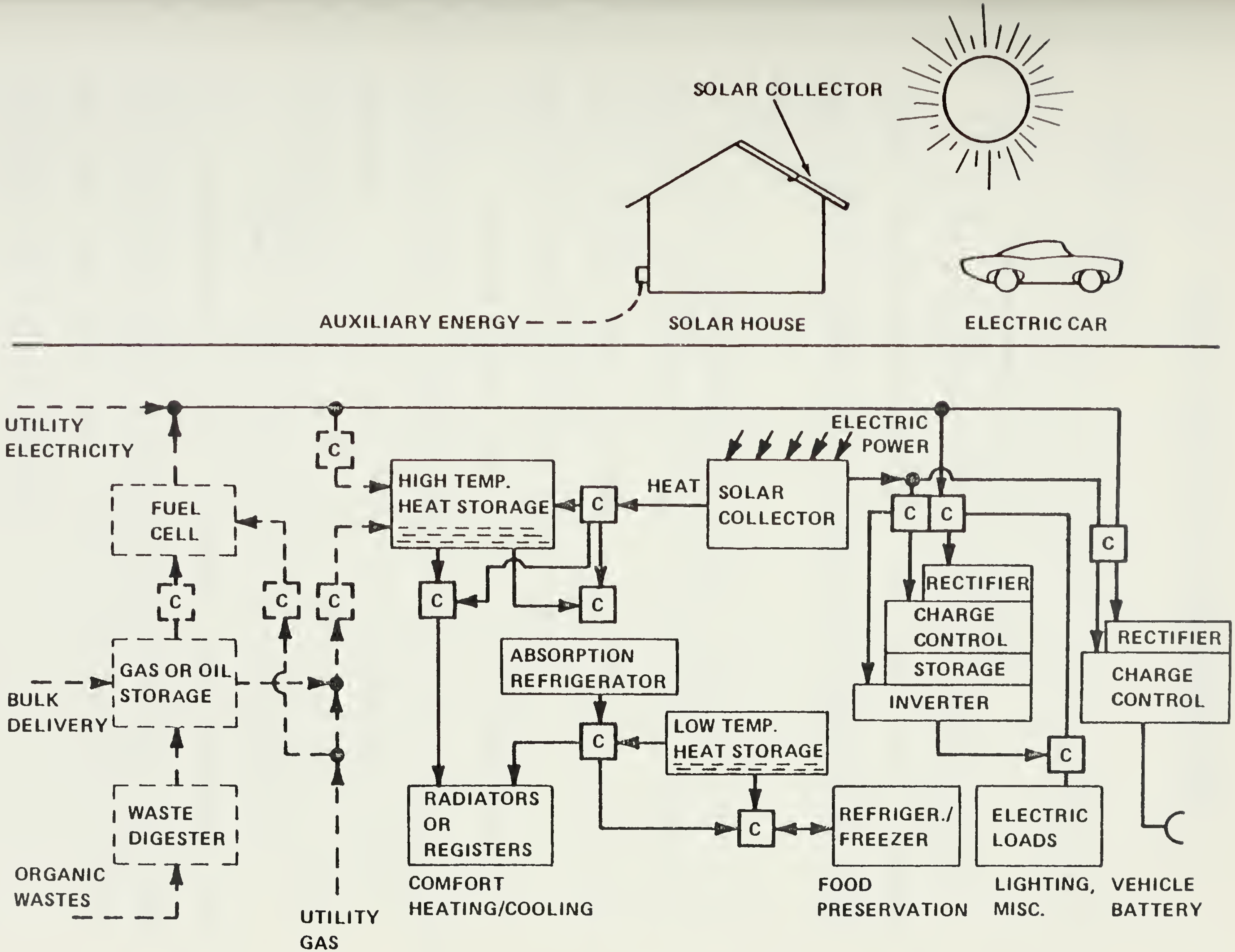


Fig. 17. Total Solar Energy Residential Application (Source: Ref. 111).

IX. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. Fossil fuel supplies will continue to dwindle in the future as projected in various energy depletion scenarios.

2. Costs of fossil fuels will continue to escalate at a faster pace than normal inflation rates due to their finite and non-renewable characteristics resulting in a corresponding increase in Navy utility costs.

3. New and less expensive alternative energy sources will be required to replace dwindling supplies of fossil fuels. Of the alternatives available, nuclear and solar energy offer the most attractive long-term solutions to the Navy's energy needs.

4. Continued Federal, State and Local government pressure on nuclear energy -- inherent radiation dangers and nuclear proliferation politics -- will continue to limit the full development potential of nuclear energy for the Navy's fleet as well as its shore facilities.

5. Although solar energy is not the panacea to the Navy's energy problems and can never completely replace fossil fuel sources in the short-term period, it offers perhaps the cleanest, least expensive, safest, and most readily abundant source of energy available to the Navy in the long-term period.

6. Participation in various public and private sector RD&D efforts will provide the Navy with a means of keeping abreast of technological and economical development that may one day provide immense power sources for a multitude of Navy operations -- in the shore establishment as well as shipboard applications.

7. Navy involvement in various Federal government sponsored solar energy programs will continue indefinitely due to the enormous facility assets and research laboratories under their control. These facility assets -- commercial as well as residential -- offer the Navy an excellent opportunity to demonstrate to the nation that energy conservation and alternative sources of energy really work in a viable energy program.

8. The Navy has approximately 80,000 units of family housing that could be converted to some type of solar energy system in the next ten years. Approximately 72,000 of these units are existing and could be retrofitted with solar energy systems; the remaining 8,000 units are of the new construction variety and solar energy systems could be integrated into their overall initial design.

9. Of all the alternative solar energy systems available to the Navy, the use of solar-water-heating systems offers the most practical application of solar for the Navy during the short-term period of from 3-5 years.

10. During the medium-term period of from 5-15 years, solar space heating and cooling, combined with water heating, offers a very attractive means of using solar energy for the Navy.

11. Photovoltaic power sources and other sources of solar energy -- wind generation, bio-conversion, etc. -- offer a viable alternative for the Navy in the long-term period of from 15-25 years -- maybe sooner if photovoltaic (solar cell) sources are substantially reduced in price.

12. It appears for the present time that single-family dwellings are better suited for solar energy conversion than larger Navy commercial/industrial facilities. Small, individual solar space heating/cooling and water-heating systems appear best suited for retrofitting of existing dwellings. Large, central space heating/cooling, water heating, and power systems for multi-unit dwellings need further RD&D efforts and "proof-of-concept" determinations before they can be applied on a large scale. Efforts are underway and several apartment-type complexes are being retrofitted with solar energy in the civilian sector, so this method may prove to be more economical and practical in the future.

13. Either ground-mounted or roof-mounted solar collectors appear to be effective for solar energy heating/cooling and water-heating systems. For retrofitting adaption, it may be more advantageous for the Navy to use ground-mounted arrays in many cases

since it has been determined that most Navy housing is not oriented to take advantage of the sun's predominately southern exposure in the Northern Hemisphere.

14. Ground-mounted collector arrays may be an excellent source of energy for space heating/cooling and water heating at remote Navy installations as part of the Navy's "forward deployment" concept as well as for contingency planning for various theaters. The ground arrays offer distinct advantages of being able to be pre-fabricated, pre-staged, and can be made air- or sea-transportable throughout the world. Setup time is greatly reduced and simplified over conventional power plants. In addition, with its modular construction and adjustable slope features, ground-mounted arrays can be readily adapted and configured for any solar energy system -- by addition of additional collector modules.

15. During the research and investigation phase in preparing the thesis, a total of 75 separate sources were contacted. As of 5 November 1977, 66 replies had been received. Information received ranged from the standard form letter indicating a firm's "name had been inadvertently placed on a mailing list" and they did not send out such information, to replies that were invaluable to the content of the thesis. The truly amazing point of the correspondence was that there was an 88% response -- twice as much as had been expected. From the overwhelming success of the correspondence, it must be

concluded that there is a lot of information available on solar energy and almost everyone is interested in sharing it.

Four of the sources responding provided computer-printed work-unit summaries or bibliographies containing solar energy information available through the particular center or exchange. These are listed separately below for information purposes.

(Report Bibliography)
Defense Documentation Center
Defense Logistics Agency
Cameron Station
Alexandria, Virginia 22314

(Custom Bibliography)
Defense Logistics Studies Information Exchange
U.S. Army Logistics Management Center
Fort Lee, Virginia 23801

(Work Unit Summaries -- Released to DOD Only)
Defense DocumentationCenter
Defense Supply Agency
Cameron Station
Alexandria, Virginia 22314

(Computer Search Summary)
Dudley Knox Library
Naval Postgraduate School
Monterey, California 93940

B. RECOMMENDATIONS

1. Continue RD&D efforts on solar energy retrofit applications in Navy family housing. This is where solar energy has the most immediate short-term potential. Various systems have already been demonstrated to be cost effective and practical -- e.g., solar water heating and space heating applications. The major short-term

use of solar energy systems in housing is through retrofitting since most of the Navy's solar energy houses of the future have already been built today.

2. Current retrofitting of existing housing units should be limited to domestic hot-water heating applications since its feasibility and economics have already been proven in various Federal government and civilian solar energy studies and projects.

3. Continue RD&D efforts in solar space heating and cooling before using on any large-scale applications.

4. The Navy needs to consider whether or not current solar energy technology could effectively support its "forward deployment" base concepts and other remote sites. A review of the "forward deployment" base energy requirements should show that there is a universal need for space heating and/or cooling, water heating, and electric power generation.

5. Use of ground-mounted, prefabricated, and mobile solar collector arrays should be investigated for use at "forward deployment" bases and other isolated or remote bases, as well as at many other U.S. shore facilities. The advantages of being able to adjust the sun angle of the ground-mounted arrays so that they can be used in any latitude, for any purpose, and transportable at any time, certainly appears to offer distinct advantages to the Navy -- especially

as applicable to the Naval Construction Battalion (SEABEE) and U.S. Marine Corps deployment facilities.

6. Solar energy systems can and should be planned for installation in new Navy facilities, taking advantage of all of nature's offerings -- the passive (or direct) solar system. Site orientation, energy conservation features (extra insulation, weatherstripping, etc.), and solar hot-water heating should be the starting point for initial investments at shore facilities.

7. Education of military and civilian employees of the Navy in energy conservation and alternative energy choices can go a long way toward helping the layman understand what is available in the future. Course material should be developed and energy subjects should be phased into all service schools -- e.g., the Naval Academy, Naval Officer Candidate School, Civil Engineer Corps Officer's School, Naval Postgraduate School, Marine Corps Officer Candidate School, various Enlisted Class A, B and C Schools, and other local activity military and civilian training courses. Education from top management to the lowest echelons (Commanding Officer to Seaman/Construction/Private) should be the goal of this energy training. (One such course, ME 3003, Energy and the Environment, is being offered at the Naval Postgraduate School as a 3-credit elective course for non-Mechanical Engineering (ME) majors starting in March 1978).

Experts from industry, and other fields of energy, can be called upon to render their expertise in the classroom, through lectures and papers, as they are currently called upon to participate in various civilian and governmental energy seminars being conducted throughout the United States. Navy support of and participation in civilian sector energy seminars should be strongly encouraged.

8. Since it appears that the greatest demand for energy is in the form of electricity, rather than heat, long-range energy planning efforts of the Navy should be directed towards investigation of photovoltaic cells and wind-generation power conversion sources. There are some unique and rather "far out" solar energy experiments being planned in the future, e.g., solar power transmission from satellites or space platforms in outer space and gigantic windmills, and the Navy should monitor these experiments for potential use in providing shore-based and possible shipboard power sources.

9. Extensive energy conservation measures should continue to be supported and enforced at all Navy activities to help preserve the dwindling supply of fossil fuels for more urgent needs -- powering ships and aircraft -- and to lower utility costs. It makes no sense to install alternative energy systems (solar energy or other) to replace our fossil fuel systems if we continue to be wasteful in our energy consumption habits.

10. Establish wind-powered generators in locations of high and steady winds. However, since effectiveness of wind power depends on the strength and steadiness of the wind, the number of places where this power can be used is quite limited.

11. Navy shore facility building designs for the future should consider the concepts evident in the "Ouroboros" house constructed at the University of Minnesota -- discussed in Chapter VIII. This "total energy" concept offers many practical and economical applications in using nature's "passive" solar energy sources in conjunction with mechanical energy sources. A good balance between the two is essential to the Navy's energy future. Although nature's energy sources offer more practical applications in smaller, individual residential housing units, their use in larger, more commercial/ industrial applications should not be ignored.

12. Solar cooking and baking concepts should be thoroughly investigated, through extensive RD&D efforts, for consideration of use with deployed Naval ground forces, e.g., Construction Battalions (SEABEES) and Marine Corps field units. The portability and ease of maintenance of small solar energy cooking and baking equipment may outweigh the initial higher costs of this equipment.

13. Solar-powered battery radios/walkie-talkies should be investigated for potential field application with deployed ground forces of the U.S. Navy.

14. An engineering study of the exploitation of the strong ocean tides/currents and river currents is justified since a majority of naval facilities are located near the oceans and are usually in the mouths of large inland-fed rivers.

15. Encourage the development and mass-production of solar devices to lower costs for producing space heating/cooling and water heating for commercial/industrial facilities, houses, and mobile homes by working with private sector contractors in RD&D efforts.

16. The major thrust of future Navy solar energy RD&D efforts should be to complement and encourage private sector (civilian) interests in solar energy systems and not to supplant it. It is clear that much basic RD&D has already been completed and the mistakes made during this process need not be repeated. It is also clear that more RD&D efforts must be accomplished before solar energy can ever be widely competitive with present sources of energy. Therefore, in planning the Navy's future energy course, clues should be taken from centuries of a more intimate relationship between humanity and nature where nature's climate reigned supreme. It would appear that the Navy has the resilience to navigate gracefully and timely this "new" course.

EXHIBIT I

PRESIDENT CARTER'S INTRODUCTION TO NATIONAL ENERGY PLAN

THE WHITE HOUSE

WASHINGTON

APRIL 29, 1977.

In each period of our history, the nation has responded to challenges which have demanded the best in all of us.

This is one of those times.

Our energy crisis is an invisible crisis, which grows steadily worse—even when it is not in the news. It has taken decades to develop, as our demand for energy has grown much faster than our supply. It will take decades to solve. But we still have time to find answers in a planned, orderly way—if we define the changes we must make and if we begin now.

This report explains why we have to act, and gives you the details of our Plan. The Plan is complicated. I am sure that many people will find some feature of it they will dislike along with features they can support. But it is a carefully balanced Plan, which depends for its effectiveness on all of its major parts.

Above all it is fair. Our guiding principle, as we developed the Plan, was that none of our people should be asked to bear an unfair burden, and none should reap an unfair advantage. There will be sacrifices, but they will be gradual, reasonable—and fair.

The changes the Plan recommends will mean a new direction in American life. In some cases heading in that direction may seem inconvenient. But I have faith that meeting this challenge will make our lives more satisfying.

We can rediscover the ingenuity and the efficiency which have made our nation prosper, rather than deepening our dependence on insecure imports and increasingly expensive conventional energy supplies. We can rediscover small-scale, more creative ways of satisfying our needs. If we are successful, we can protect jobs, the environment, and the basic American standard of living, not only for ourselves but also for our children and grandchildren.

I know that, if we work together as a united people, we will succeed.

EXHIBIT II

FACSIMILE COPY OF PROFESSOR OTTO ECKSTEIN'S COMMENTS ON SOLAR ENERGY

DATA RESOURCES, INC. 29 HARTWELL AVENUE · LEXINGTON · MASSACHUSETTS 02173
617 / 861-0165

OTTO ECKSTEIN
PRESIDENT

April 20, 1977

Mr. Bruce B. Geibel
Lieutenant Commander
Civil Engineer Corps
Naval Postgraduate School
SMC #2171
Monterey, California 93940

Dear Mr. Geibel:

The quote in Time Magazine came out a bit stark, but its meaning is correct, I believe. In the political context, a focus on solar energy really means that the person involved is not willing to deal with the near-term problems which pose some really tough choices. To be for solar energy, and to pour a few more hundred million dollars into some kind of research in that direction, is a pretty noncontroversial business. But now to get the American people to conserve energy use and to get them to be willing to pay the full market value of energy, those are tougher matters to deal with.

There also is the question of the time schedule of the energy crisis. Solar energy may make a small but significant contribution to total energy supplies by 1990, and it is a good idea to get started on this technology. But, as the President indicated last night, the energy crisis is upon us now, and the question is how we get through the next 14 years first.

Thank you for your comment.

EXHIBIT III

SPECIAL SURVEY OF NAVY AND MARINE CORPS FAMILY HOUSING

(Solar Heating and Cooling Demonstration Act)

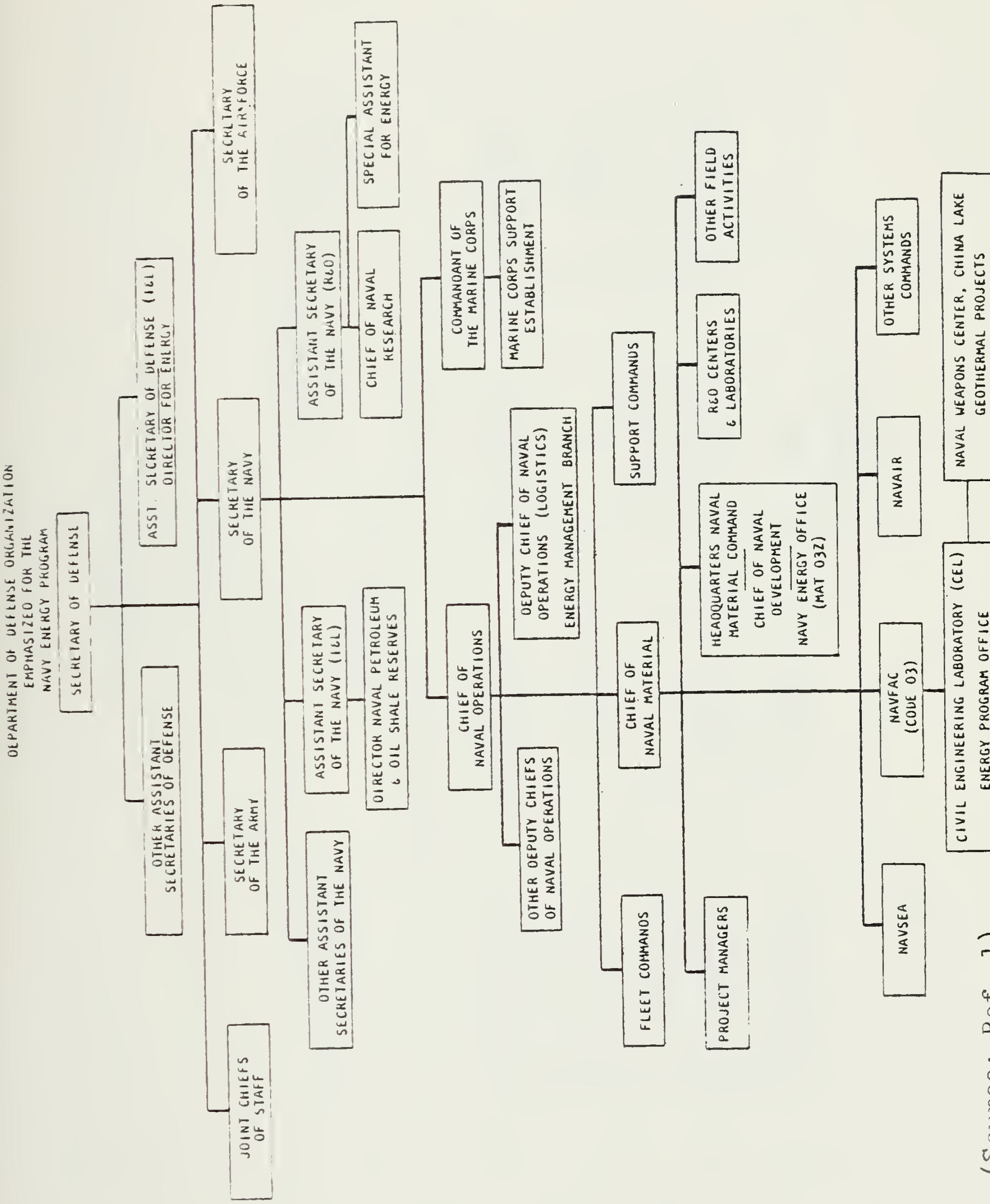
- Extension (Oct 76) of (June 76) Study. From 47 to 121 Sites and From 58,000 to About 86,000 Family Units.
- Estimated Family Housing Energy Consumption, FY-75:

Description of Use	Estimated Applicable Units	Used (10^{12} BTU)	Relevant Stastics
Total, All Types	93,000	22.6	12% of Shore Usage
Electricity	93,000	12.0	53% of Total, All Types
Fuels	93,000	10.6	47% of Total, All Types
Space Heating	76,000	4.67	44% of Fuels
Space Cooling	58,000	3.11	26% of Electricity

(Source: Naval Shore Establishment Energy Research & Development Program First FY-77 Program Review).

EXHIBIT IV

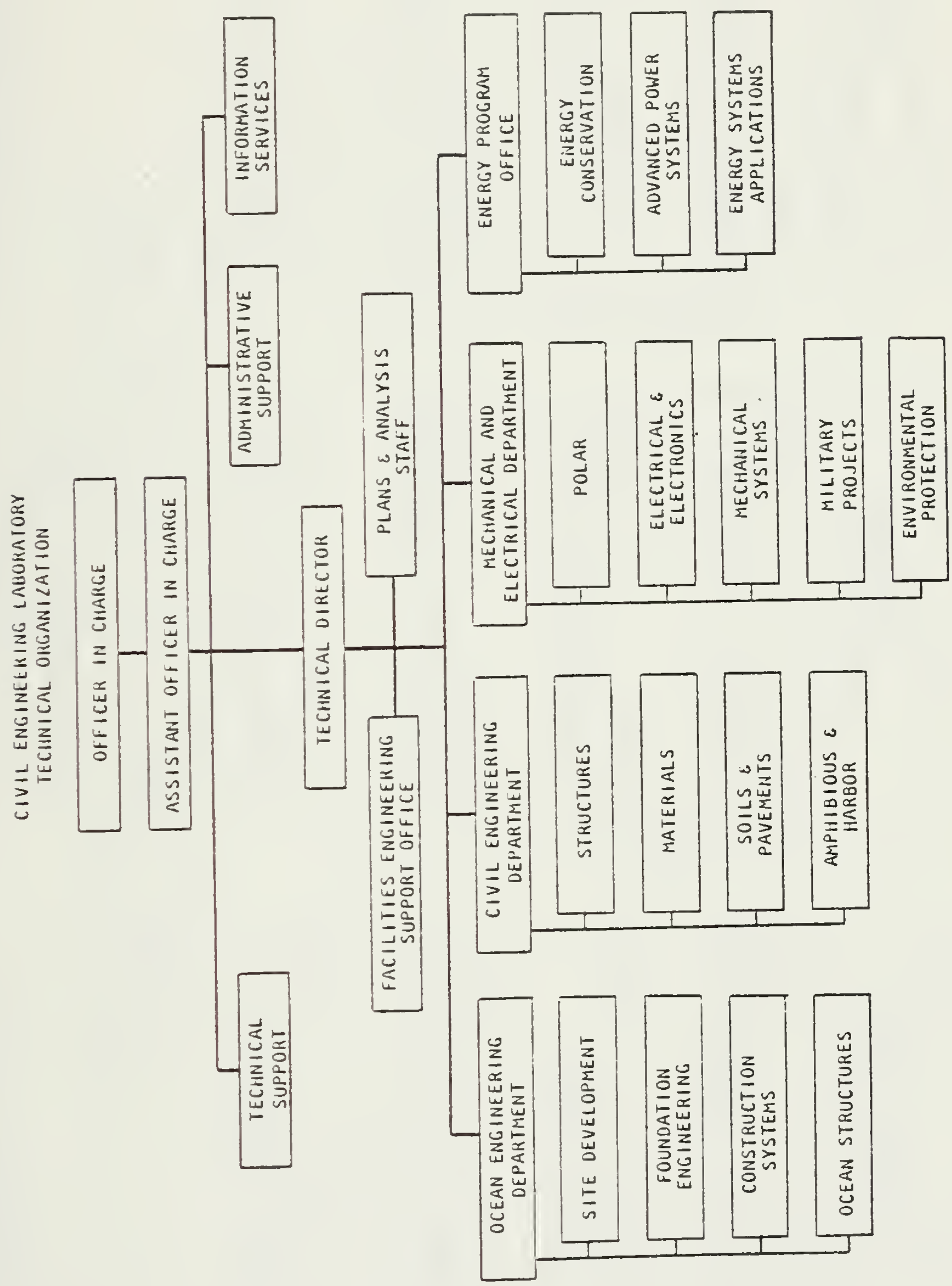
DEPARTMENT OF DEFENSE ORGANIZATION CHART



(Source: Ref. 1)

EXHIBIT V

ENERGY PROGRAM OFFICE ORGANIZATION (CEL)

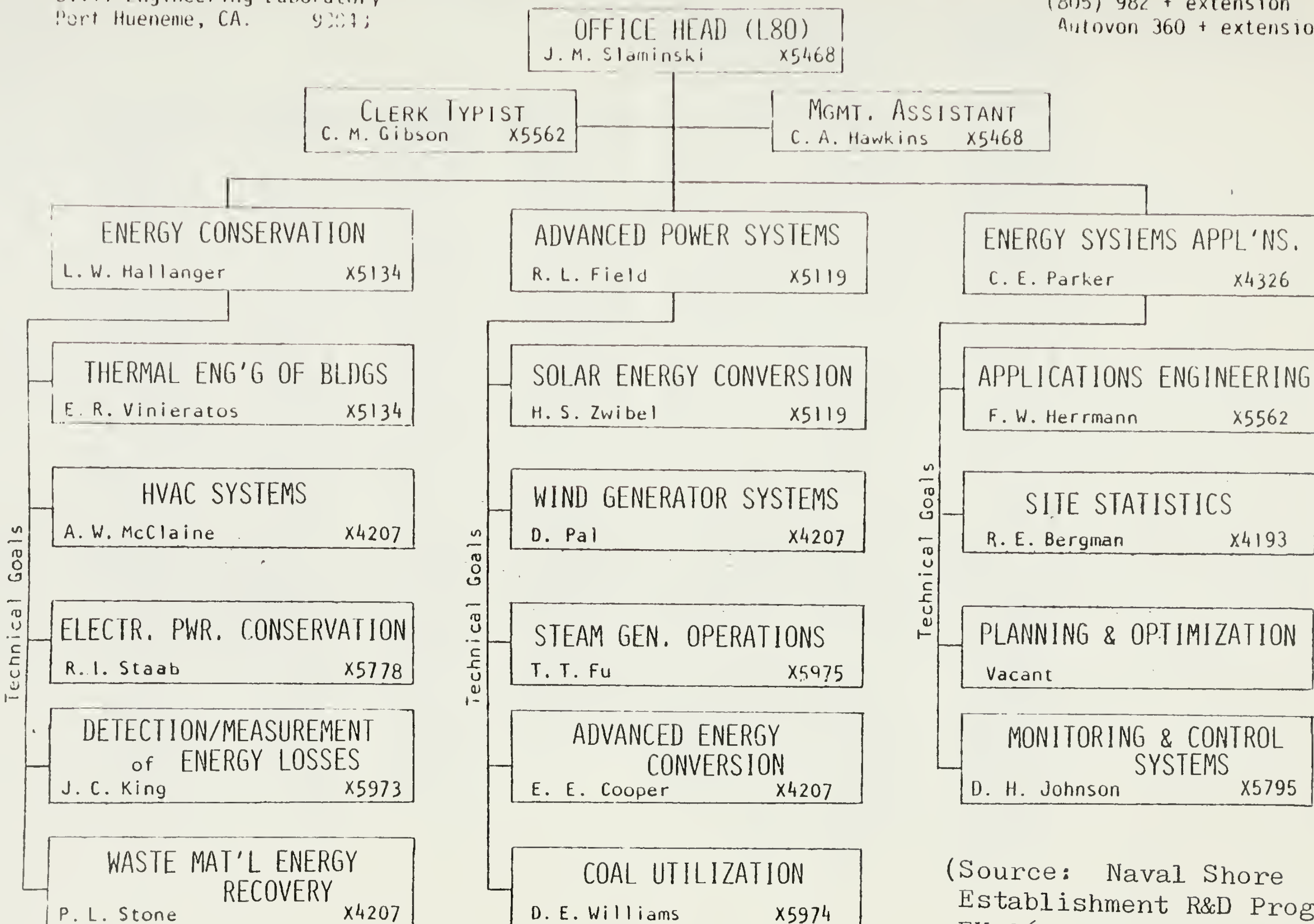


(Source: Ref. 1)

ENERGY PROGRAM OFFICE - FUNCTIONAL ORGANIZATION

Energy Program Office
Civil Engineering Laboratory
Port Hueneme, CA. 93043

Telephone:
(805) 982 + extension
Autovon 360 + extension



(Source: Naval Shore Establishment R&D Program, FY-76 Program Review)

EXHIBIT VI

IDENTIFYING RETROFIT CANDIDATES

There are numerous engineering and government manuals that include building retrofit projects that will save energy. The examples provided in those manuals are based on the success of similar projects in prior applications. The method provided here is designed to build on this success by relating the appropriate, proven projects to specific energy use systems that can be easily identified in a given building or facility.

The method employed parallels that used in a full-scale engineering survey. However, checklists, reference tables, and simple calculations based on the experience of others are substituted for the more complex analysis and measurements entailed in a full-scale engineering effort. The method, of course, cannot provide the precision of an engineering study, but it is not intended to. Its purpose is only to identify sound retrofit projects and provide approximate measures of their relative merits for budgetary planning, not to develop engineering designs of the projects themselves. Therefore, the survey method was streamlined and simplified so that it requires a minimum investment of time and resources. An overview of the suggested method to be employed for an individual facility is shown in Figure 1.

- *Step 1 — Collecting Energy Use Data:* This step provides fuel cost data necessary to calculate cost savings in a later step, and also provides an overall sense of priority for retrofit projects. Fuel forms that account for the largest part of the total fuel bill should receive greatest emphasis in planning retrofit projects.

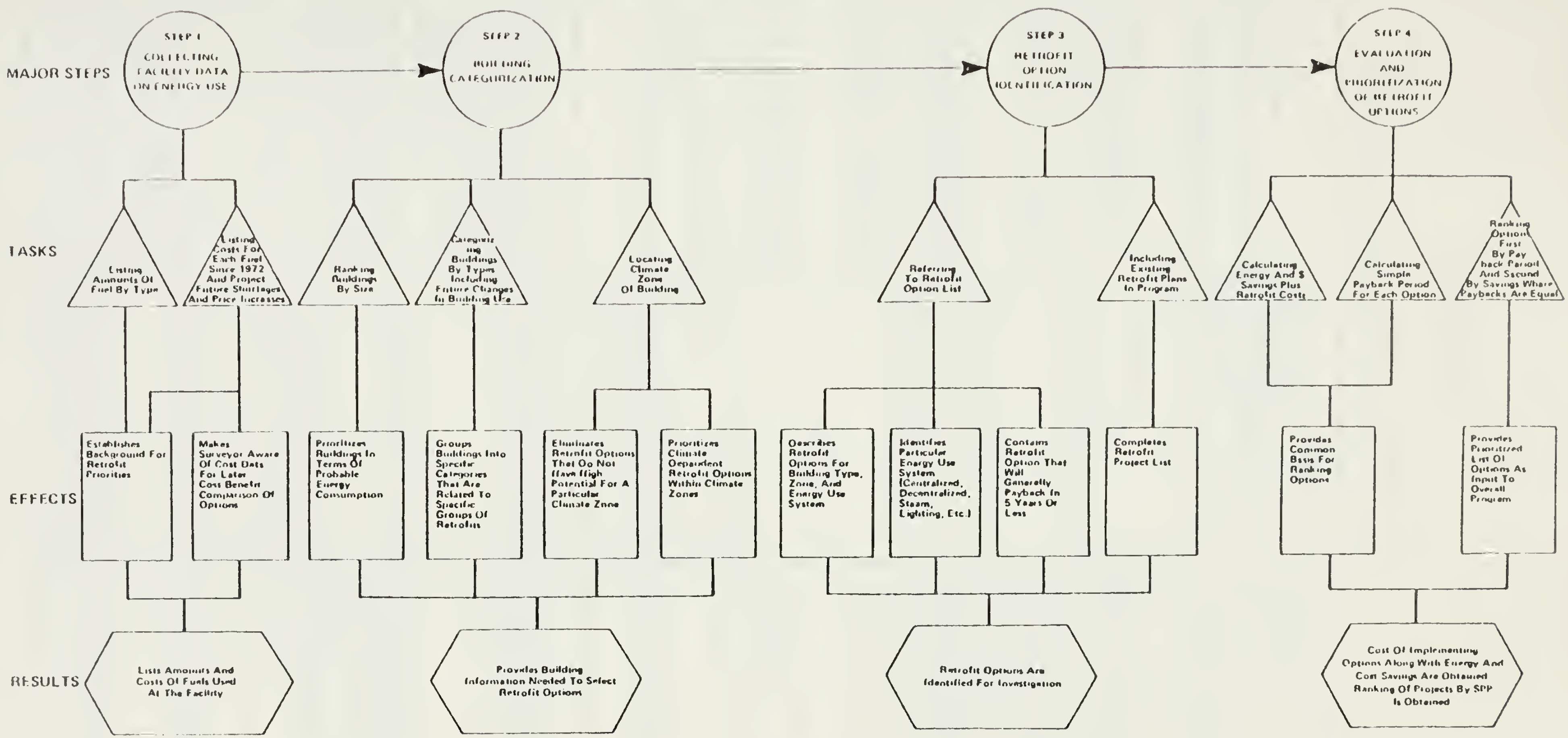
- *Step 2 — Categorizing Buildings:* In this step, all of the buildings at a facility are ranked in terms of size, and thus by their probable proportion of energy use; buildings are categorized into types; and the climate zone that corresponds to a facility's location is identified.

- *Step 3 — Identifying Retrofit Options:* In this step, reference tables link appropriate candidate retrofit options with specific energy systems as a function of building type and the climate zone in which the building is located. In addition, retrofit projects already planned can be easily incorporated.

- *Step 4 — Evaluating and Ranking Retrofit Projects:* In this step the energy and cost savings of individual retrofit projects are calculated, along with their associated investment costs. The options are then ranked in terms of the time it would take for them to pay back their investment cost.

(Source: Ref.68)

Figure 1 STEPS IN BUILDING RETROFIT IDENTIFICATION SURVEY



(Source: Ref. 68)

EXHIBIT VII

SOLAR SYSTEM CHARACTERISTICS

Summary of solar system characteristics from *Designing and Building a Solar House*, © Donald Watson, 1977.

	1. Passive Systems: Solar Windows	2. Passive Systems: Collector/Storage Building Elements	3. Active Systems: Flat-Plate Collectors
CLIMATE			
Hot Dry:	Recommended for use with other passive systems: must be protected against summer sun to prevent overheating.	Recommended for near full-capacity heating and (with Skytherm-type systems) cooling.	Only domestic hot water or auxiliary spaceheating systems (active) are required, with appropriate passive design.
Hot Wet:	Acceptable if summer ventilation fully operable: shading, insect screening and storm protection also required. Ventilating roof monitor recommended.	High thermal mass in structure not desirable in this climate.	Domestic hot water heating, auxiliary space heating, pool heating and heat pump systems most practical. Solar-powered cooling may become practical in future.
Temperate:	Recommended for use with other passive and active systems: both undesired heat gain and heat loss must be considered. Greenhouses may be fully solar-heated.	Thermal capacity desirable, with controls against overheating.	Auxiliary space heating (including domestic hot water heating) recommended, with window-heat recovery system. Heat-pump system practical if air conditioning is required. Single glass collectors and site-fabricated collectors are sufficient.
Cool:	Recommended for use with other active systems: insulation against nighttime heat loss required. Use of ventilating skylights may eliminate need for air conditioning	Thermal capacity necessary: insulation against heat loss required.	Large-capacity solar heating recommended in sunny, cool locations. Well-fabricated and efficient collectors are required. Air systems avoid problems of freezing.
HOUSE TYPE			
Existing House:	Add shading and insulating devices to improve suitability of windows: insulating draperies the best first investment in improving energy efficiency of existing houses.	Difficult to install in existing houses.	Requires acceptable location and orientation of collectors, usually on special frame support on existing roof or ground.
Existing Apartment:	Options may be limited to interior insulating shades and draperies. Skylights added to roofs for light, air and view can also be used for winter day heat.	Difficult if not impossible to install.	Roof area may be available for small collector area (recommended for domestic hot water heating).
New House (detached):	East, south, and west windows can be used for winter heat gain: south windows preferred for ease of control against summer overheating.	Adequate wall and roof areas are available for effective arrangement of passive elements.	Ideal for proper sizing and orientation of required collector area.
New Apartments:	Most windows should face south: balconies can be used for summer shading.	Reduced wall and roof areas limit options: glass-covered masonry collector/storage walls well suited to multi-storied construction.	May be limiting in available area for collectors. Single large collector area, which supplies several units, may be practical.
CONSTRUCTION METHOD			
Owner-Built:	Standard sizes of insulated glass can be purchased for installation in site-built frames (also with insulating systems such as Beadwall). Otherwise use high quality, well-insulated windows with self-flashing mounting flanges. Greenhouses can be purchased as kits or fabricated from re-used window sections if well installed to prevent air leakage around frames.	Several masonry block systems can be easily installed by self-helpers: Drumwalls easily installed: Skytherms currently being used in self-help projects.	Site-built collectors must be carefully made, especially to prevent air leakage, condensation damage and glass breakage. Air collectors and water-trickling collectors commonly used for low initial cost.
Built for Sale:	Solar-oriented windows can usually be included in normal construction cost and sale price: conventional building plans can be improved in window orientation, internal zoning and heat flow without adding to construction cost.	Suitable in order to make necessary design adjustments to climate, site and to owner's lifestyle	Liquid systems commonly used because of flexibility of installation and availability. Even if initial installation is small (domestic hot water or auxiliary space heating), space should be left for enlargement of system in future.
Custom-Built:	Views can be coordinated with solar windows. Internal zoning recommended to create greenhouse or sunrooms.	Passive systems may be unfamiliar to house-buying public: interior temperature swings and insulating devices may be unacceptable to buyers.	Ideal for proper integration of collectors into house design and construction, adapted to specific sites.
FINANCING METHODS			
Short-Term Investment:	Solar windows recommended because of low initial cost: interior temperature swings or insulating controls that require manual operation may not be acceptable to next buyer.	Unfamiliar passive systems may limit resale of house.	Domestic hot water heating and auxiliary space heating have shortest payback period.
Long-Term Investment:	Effective insulating panels or draperies recommended, even though more costly to install, for considerable long-term savings.	Because of specific nature of design and use, passive systems with collector/storage building elements are best suited to long term investment (custom design, single ownership)	Uncertainty of future fuel availability and its cost warrants consideration of large-capacity systems over the long term.

	4. Active Systems: Advanced Solar Collectors	5. Active Systems: Storage	6. Active Systems: Distribution
CLIMATE			
Hot Dry:	Not necessary for space heating. Clear sky conditions make focusing collectors effective (for high-temperature applications).	Active systems require storage sized for only one day carryover, because of high frequency of sunny winter days.	Active systems of heat distribution (fan operated) recommended to control heat imbalance. Nighttime regenerative cooling of rock storage possible in summer.
Hot Wet:	May be required for solar-powered cooling applications. Not necessary for heat pump installations.	Large storage capacity not required because of low heat demand.	Warm-air distribution systems give most flexibility for humidity control and air cooling options.
Temperate:	Diffuse sky conditions and medium temperature requirements flavor flat-plate collectors.	Storage can be sized to available collector area; near 100 percent solar heating possible, although smaller capacity is more justified in current economic terms.	Any distribution system applicable. High supply/low return air distribution appropriate.
Cool:	High-performance collectors may be required to reduce collector area needed.	More than two days carryover not practical due to large storage size required with current sensible heat storage methods.	Any distributor system applicable. High supply/low return air distribution can be used only if usual cold drafts at windows, entries and stairs are eliminated
HOUSE TYPE			
Existing House:	High-performance collectors may be required if only limited collector area available.	Generally difficult to install required storage volume due to limited space, except outside the house. Smaller, latent heat-storage methods may solve this problem.	Existing hydronic (baseboard) can be used only with solar collector-heat pump combination to increase delivery temperature. Existing warm-air distribution ducts can be used if large enough (sized for air conditioning).
Existing Apartment:	Flat roofs may provide good areas for tracking and reflecting collector designs.	Difficult, if not impossible, to install required storage.	Generally difficult to use existing distribution systems, except as noted above for existing houses.
New House (detached):	Not necessary if proper space available for flatplate collectors.	Recommended to incorporate storage in house foundation or basement.	Any distribution system can be used. Warm-air system recommended for utilization of lower temperature from storage.
New Apartments	High-performance collectors may be required if only limited collector area available.	Party walls and masonry structure can be used as low-temperature (passive) storage mass. Low heat loss (compared to detached dwellings) results in reduced storage volume requirements.	If central heating plan is used, long distribution runs may require hydronic system.
CONSTRUCTION METHOD			
Owner-Built:	Honeycomb heat trap and other reflecting collectors can be built by self-helpers. However, patent use rights may be required.	Rock storage requires on-site labor, therefore is cost-effective for self-helpers. Liquid storage systems require plumbing skills.	Air distribution systems are usually easiest to install, but must be air-tight and well insulated. Liquid systems require plumbing skills.
Built for Sale:	Advanced collectors not yet cost-effective in the built-for-sale market.	Slab-on-grade construction may favor rock-type in-foundation storage enclosure.	Any distribution system can be used, although warm-air distribution is recommended as noted above under New House (detached). Air supply registers must be carefully located to avoid low-temperature air drafts.
Custom-Built:	May be appropriate to suit special requirements of design or structure.	Any storage type can be properly incorporated in custom design.	Same consideration applies as noted above for built-for-sale construction. Special requirements of natural convection in double-height rooms can be met with careful design of distribution system.
FINANCING METHOD			
Short-Term Investment:	Advanced collectors not yet sufficiently available to be cost-effective for short-term payback in residential application.	Small storage system or use of construction mass (masonry walls, etc.) for storage, most cost-effective for low initial investment.	Warm-air distribution systems recommended, with active solar systems, offering greatest flexibility for future re-sale or system improvements (air cleaners, humidity controls, cooling).
Long-Term Investment:	A long-term investment analysis may show that advanced collectors are cost-effective over the long term.	Larger investment in full storage capacity with proper controls is justified over the long term.	Same as above.

APPENDIX A

DEPARTMENT OF DEFENSE ENERGY CONSUMPTION STATISTICS

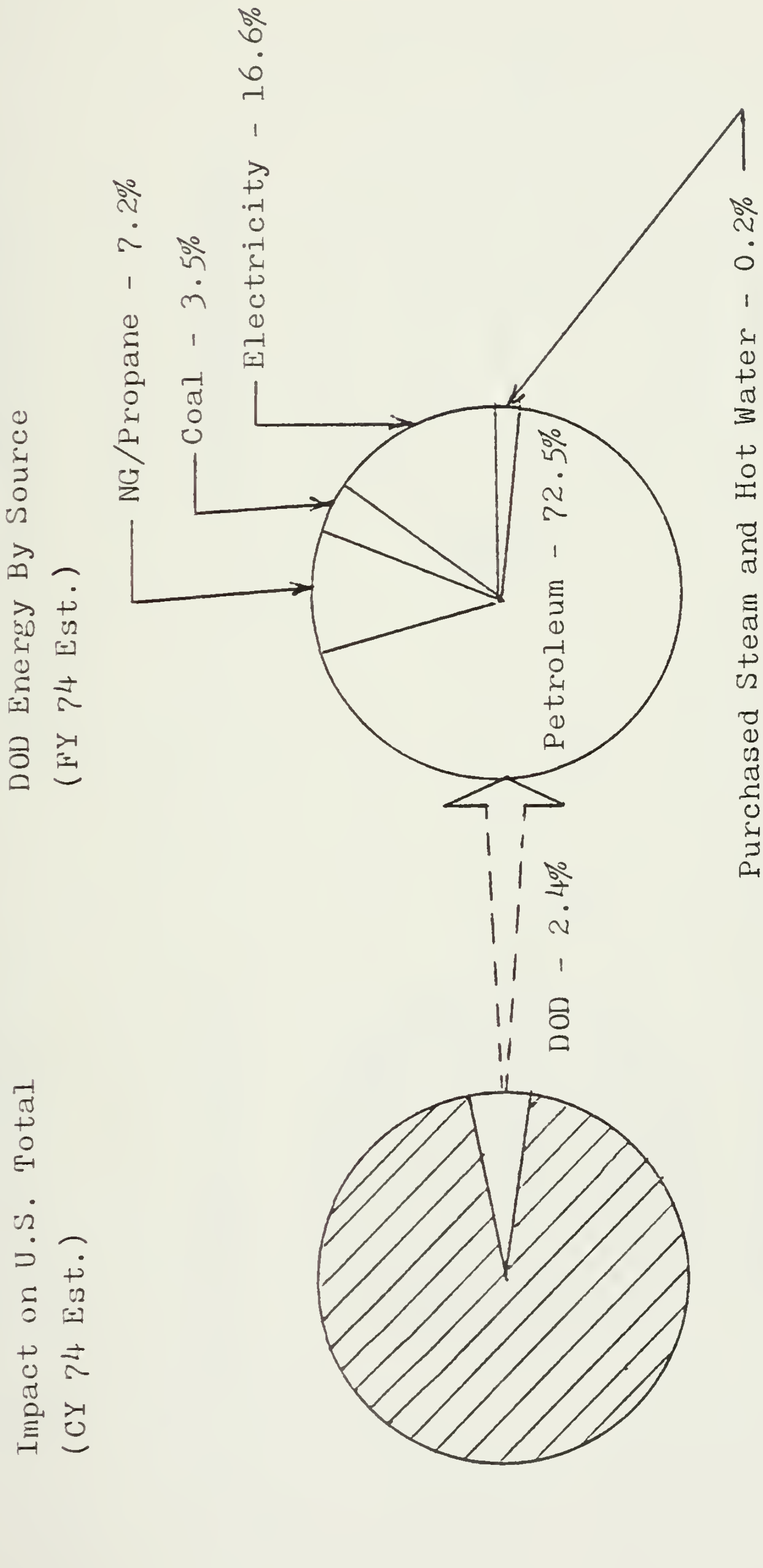
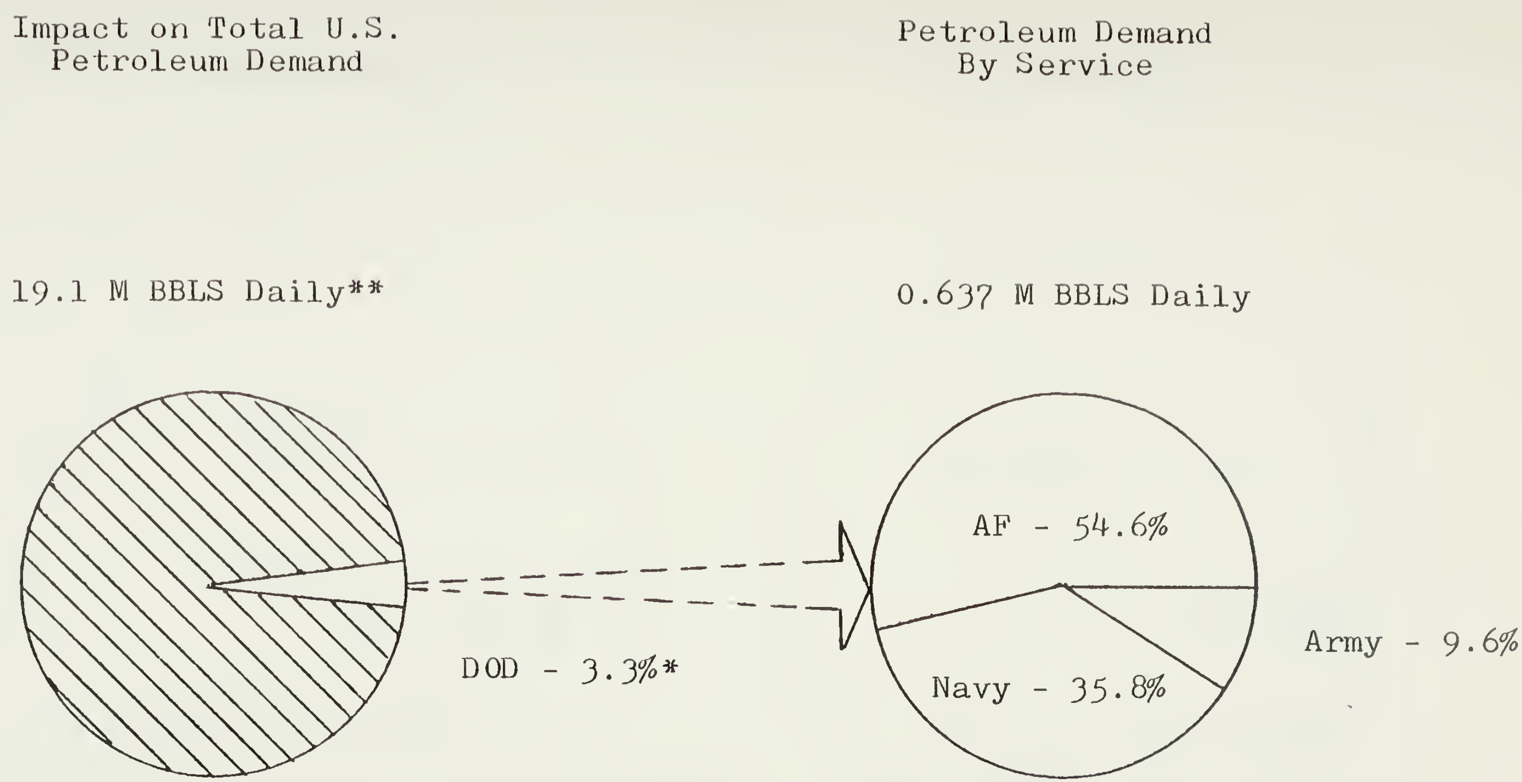


Figure A-1 - Total DOD Direct Energy Use (Excluding Nuclear)
(Source: Ref. 3).



*50% Procured From Foreign Sources Prior to the Embargo
**FEA Forecast for CY-74 (2 January 1974)

Figure A-2 - Total DOD Petroleum Energy Demand (FY 74 Est.)
(Source: Ref. 3).

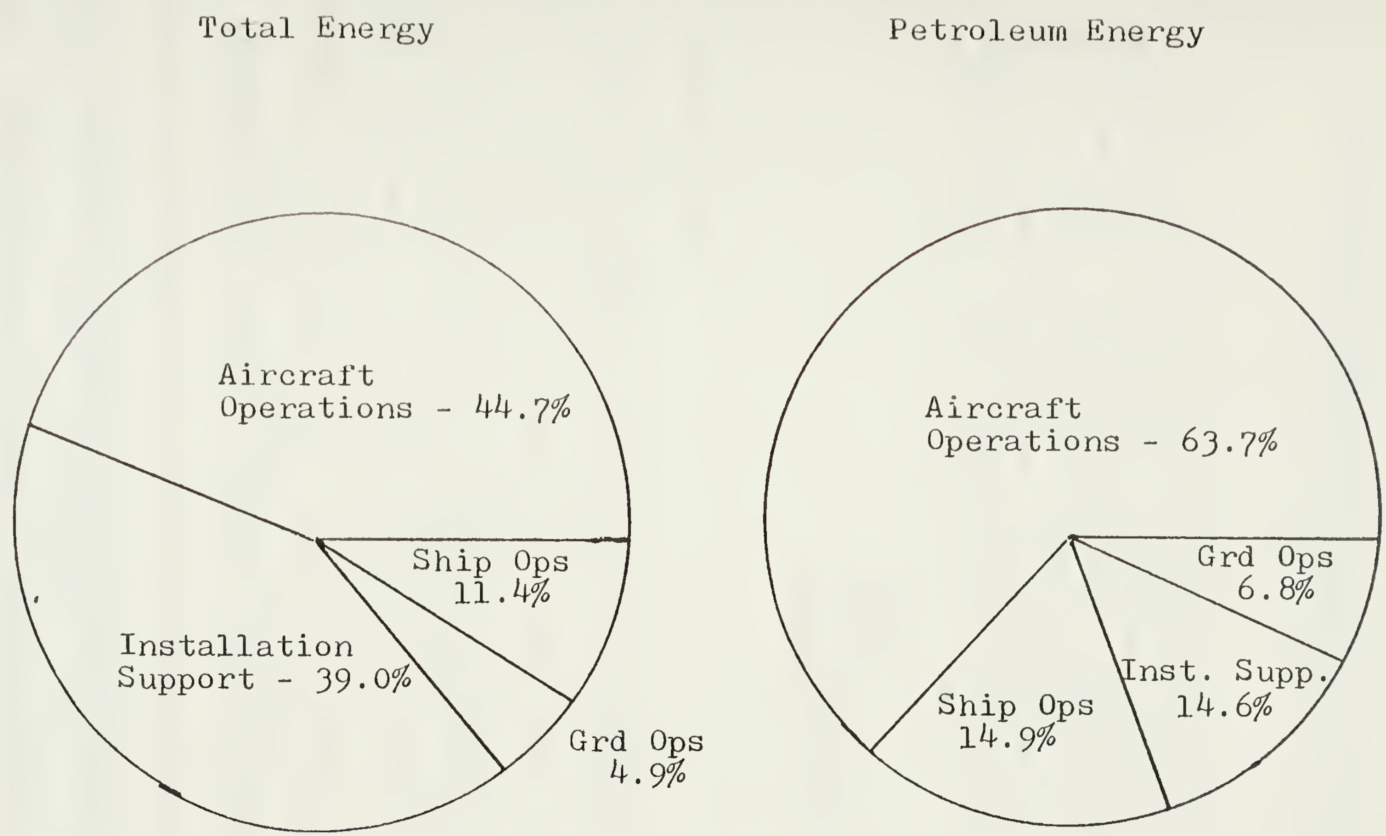


Figure A-3 - Total DOD Energy Demand By Operational Function. (FY 74 Est.) (Source: Ref. 3).

APPENDIX B

TECHNIQUES FOR LIFE-CYCLE COSTING ANALYSIS OF ALTERNATIVE ENERGY SYSTEMS

Solar energy is not a cure-all for our energy problems -- just one part of a larger strategy that involves energy conservation, good design, and maybe a modest sacrifice of convenience. The sun's potential is often oversold. Experts disagree widely about which systems work best and are most cost-effective. Many installations are frankly experimental. And a full-scale solar system typically involves considerable cost and technical ability.

Sunset
The Magazine of Western Living
November 1976

A. BACKGROUND

There are a number of different ways to perform a benefit-cost analysis or life-cycle cost analysis on solar energy systems to determine whether or not they are economically competitive with other similar systems -- e.g., solar system versus fossil fuel system -- and whether consideration should be given to installing the system in new construction or trying to retrofit it into an existing facility. An in depth review and explanation of the various ways to perform an economic analysis on various energy systems is given by Rosalie T. Ruegg, Solar Heating and Cooling in Buildings: Methods of Economic Evaluation. Several of the methods of analysis discussed by Ruegg will be looked at briefly in this appendix.

In the near future, solar water and space heating will probably become more a matter of necessity than of economic preference as our fossil fuels continue to diminish in quantity available for use. Whatever the case -- economics or necessity -- there needs to be some measurement of economic comparison between the competing systems. For example, conventional fossil fuel systems, particularly water heating, are characterized by a fairly low initial investment which must be supplemented by high operating costs (maintenance and fuel bills). Solar water heaters, on the other hand, carry a high initial investment, but since the "fuel" is free sunshine and the maintenance is minimal due to the simplicity of the system components, the operating costs are very low. Therefore, rather than making monthly payments for water heating, the Government purchasing solar water heaters must make a high initial investment which will be amortized over a period of time through negligible fuel bills -- this is called "life-cycle" costing, or looking at the cost of the system over its economic life.

B. INITIAL INVESTMENT VERSUS LIFE-CYCLE COSTING

Embodied in the previous paragraph is a relatively new approach to calculating the economic viability of systems. Traditionally, a large number of items sold in the U.S. have been purchased on the basis of initial costs with little or no attention given to future maintenance, repair, or operation costs; e.g., homes, automobiles,

heating and cooling systems, and appliances. However, the recent rapid escalation in fuel prices and labor and material costs for maintenance has created a whole new ball game for the Department of Defense, U. S. Navy, and the Federal government, not to mention the average individual in this Nation, so far as determining the actual cost of an item or system. It is now extremely important to consider the entire cost of a particular system over its life-cycle, not just its initial investment cost.

> With life-cycle costing, the consumer tries to evaluate total costs over the life of the system rather than looking strictly at initial cost. Americans have tended to be very "first cost" conscious, ignoring the life-cycle costing principles. Although life-cycle costing is a more accurate indicator of economic viability than first cost, life-cycle costing is somewhat complex and runs counter to an American tendency to disregard the long-term for the short-term. [Ref. 100].

C. FISCAL-CYCLE VERSUS LIFE-CYCLE COSTING

In regards to application of life-cycle costing in the Navy, every defense program -- no matter how large or small -- must be able to generate, at all times, a "yes" answer to three very important questions:

Is it needed or wanted by the Navy?
Is it technically feasible?
Is funding available to develop or deploy it?

To best answer these three questions, all programs are constantly subjected to parallel decision cycles. One, they pass through the

"fiscal cycle" each year of their lives. Two, they pass through their "life cycle" just once in their lives. It is during this life cycle that the solar energy program goes from basic research and being just a "gleam in someone's eye," through development, production, demonstration, and actual deployment as a useful system.

While the Army, Navy and Air Force do use some common documents during life-cycle analysis of various defense systems, particularly when they must interface within common DOD projects, each has its own internal decision making and approval procedures along with unique documents that form the basis for these decisions and approvals. Thus, because either the "fiscal" or "life-cycle" process can directly impact a program, in particular one in solar energy areas, it is important that both be thoroughly understood. It is not the purpose of this thesis to provide a complete and thorough understanding of the "fiscal" or "life-cycle" processes, but merely to point out that they are both important. Therefore, the reader is directed to several sources for additional background information that the author has found to be quite interesting and informative. These are:

1. Fiscal & Life Cycles of Defense Systems, by the Pomona Division of General Dynamics, Third Edition, March 1976, reprinted by the Navy Logistics Management School.

2. Ruegg, Rosalie T., Evaluating Incentives for Solar Heating, NBSIR 76-1127, Final Report, National Bureau of Standards, U.S. Department of Commerce, September 1976.

3. Beck, E. J., Jr. and Field, R. L., Solar Heating of Buildings and Domestic Hot Water, Civil Engineering Laboratory, Technical Report No. R-835, January 1976.

4. McGarity, A. E., Solar Heating and Cooling: An Economic Assessment, NSF No. 75-37, National Science Foundation, 1975

5. Ruegg, Rosalie T., Solar Heating and Cooling in Buildings: Methods of Economic Evaluation, NBSIR 75-712, Final Report, National Bureau of Standards, U.S. Department of Commerce, July 1975.

6. Department of Defense Instruction 7041.3, Economic Analysis and Program Evaluation for Resource Management, 18 October 1972.

7. Kreider, J. F. and Kreith, J., Solar Heating and Cooling: Engineering, Practical Design, and Economics, McGraw-Hill Book Company, 1970.

D. LIFE-CYCLE COSTING VARIABILITY

The economic feasibility of solar space heating and cooling and water heating is highly dependent on the ability of the solar equipment to provide energy and on the amount of energy required each year to heat and cool the dwelling and heat its water. This dependency makes

the economic evaluation highly specific to particular location -- e.g., varying degrees of solar radiation is received in specific locations, fuel costs differ from place to place, and material and labor costs are of course variables in most locations. In fact, there are so many variables that exist today when figuring life-cycle costs that it has been necessary to computerize many programs used in calculating life-cycle costs for solar energy and fossil fuel systems. Mathematical models programmed on computers can accurately simulate the operation of solar heating and cooling systems at any location for which temperature and solar radiation (insolation) data is available. Several models available for computation of solar systems versus conventional systems are discussed in Appendix C.

Before these models are discussed, it will be advantageous to first look at an overview of life-cycle costing so that we may see the various steps involved in its application along with identification of relevant cost items used in its formulation. Addititionally, we will look at the results of several major Federal government, Department of Defense, military service and private sector studies of solar energy costs. While life-cycle costing is not new to industry, and the Federal government in general, it is not widely used in the residential market. So, while an individual may be convinced of the value of looking at the long-run benefits and costs, he may have some questions about the methods now being used. It is the purpose, therefore, of

the remainder of this Appendix to briefly examine the various rules and assumptions and to provide a guide to further references for methods of solar energy system calculations.

E. AN OVERVIEW OF LIFE-CYCLE COSTING TECHNIQUE

The basic technique of life-cycle cost analysis is one that considers total relevant costs over the life of the system, including costs of research and development, acquisition, installation, maintenance, operation, and where applicable, retrofitting and disposal costs. It is a useful concept, not only for collection of data for the purpose of design or ownership alternatives, but also for the purpose of future analysis. Life-cycle costing is an appropriate approach for comparing fossil fuel systems with alternative energy systems in both the Federal government and the private sectors of our economy.

Its specific relevance to the U.S. Navy is grouped under six major steps for performing life-cycle cost analysis on solar systems in general. These six steps are briefly discussed below.

1. Specification of Objectives and Constraints

The relevant life-cycle cost objective is to achieve a desired level of thermal comfort, whether it be in a commercial building or residential home, and a desired water temperature for hot water at the lowest cost. The objective is subject to several constraints however, such as safety, retrofitting, and/or aesthetic qualities.

2. Identification of Alternative Solutions

There are a number of possible alternative approaches to the objective. They include use of conventional systems -- natural gas, propane, oil, electricity, electric heat pumps, etc. -- for space heating and cooling and water heating. The alternatives would also include energy conservation investments, such as insulation and weatherstripping, and alternative energy investments such as solar energy systems. Generally, the alternatives are simply different combinations of solar systems, energy conservation measures, and conventional energy systems.

3. Identification of Relevant Costs

A number of factors must be considered when calculating relevant life-cycle costs of solar systems. The more important ones have been summarized by Alan Okagaki and Ken Bossong [Ref. 100] and Rosalie T. Ruegg [Ref. 34] as follows:

a. System Acquisition Costs

Includes search costs, purchase prices, delivery costs, and installation costs. Other costs can be presumed if RD&D efforts, retrofitting costs, etc., are part of the process.

b. Operating Costs

These are primarily fuel costs in conventional systems. Since the dollar savings that will accrue from the initial investment

are directly proportional to the fuel prices, local fuel prices have a tremendous impact on the economic viability of the solar water heating system.

c. Inflation Costs

Energy price increases are assumed to be a matter of fact for the future. The faster conventional fuel prices rise, the more economically attractive solar systems will become in the future -- it is assumed here that fuel prices, which have risen faster than the general inflation rate in the past recent history, will continue to rise faster in the future. Inflation costs specified in NAVFAC Instruction 4100.6, of 29 March 1977 (see latest update for current estimates), make the following projections for real annual cost increases in conventional fuels, and recommends their use where local projections are unreliable or unavailable:

Natural Gas	- 7% per year
Oil (No. 2 Fuel Oil)	- 9% per year
Coal	- 7% per year
Electricity	- 3% per year
Material and Labor	- 3% per year

Appendix E contains additional information on annual fuel inflation factors and discounting for real inflation as applicable to all Navy projects. If and when Congress sees fit to enact legislation to deregulate natural gas prices, one might expect to see a

quantum leap upwards in the price of natural gas in one or two giant steps which will throw the aforementioned percentages out of kilt. This could create a situation where solar energy fuel becomes competitive with natural gas in most locations in the U.S. the same as with electricity.

d. Solar Insolation

As stated earlier, solar energy insolation varies with the geographical areas of the U.S. Existing systems can provide between 65% and 90% or more of the total energy required to heat water depending on its insolation value. The insolation values for specific locations can be found in numerous documents and texts and therefore will not be listed in their entirety in this thesis.* Solar insolation is measured in Langleys (=3.688 Btu/ft^2). The amount of insolation received at any location depends on the hour of the day, day of the solar year, and amount of cloud cover present. Some heat is available on a cloudy day. Most of the sun's energy received is in the visible and infrared portions. Monthly average and yearly average

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*Sources for obtaining solar insolation data for specific locations include the following: Anderson, B. and M. Riordan, The Solar Home Book: Heating, Cooling and Designing with the Sun, Cheshire Books, 1976; Environmental Science Services Administration, Climatic Atlas of the United States, Washington, U.S. Department of Commerce, 1968; Dawson, J., Buying Solar, Federal Energy Administration, Department of HEW, June 1976.

daily insolation data for numerous Naval installations are given in Appendix D. In general, the higher the latitude, the less insolation is received on a horizontal surface.

e. Pay-Back Period

This is defined as the length of time necessary to fully amortize the initial investment disregarding any time value of money. The pay-back period is one of the most critical factors to be considered in evaluating the viability of solar water heating systems, or any solar system for that matter and is a separate calculation from the life-cycle costing (which takes into consideration the time value of money).

Current DOD and Navy policy requires that energy related projects amortize themselves within 6.0 years except for solar energy projects which are exempt from this policy. They must be self-amortizing (meaning pay-back over the life cycle) and will be considered on an individual basis. [Ref. 62].

f. Discount Rate.

When the benefits of a proposed system are derived in different time periods than those in which the costs are incurred, the proposal cannot be evaluated unless these differences in timing patterns are taken into account. This is especially true in alternative energy system evaluations, where operation and maintenance costs (or savings) are experienced over the life-cycle of the equipment. This requires the use of a discount rate. Thus, a proposal to acquire

an expensive solar energy system that requires minimal annual maintenance can be compared with a proposal to acquire a less expensive fossil fuel energy system that requires higher annual maintenance since the two streams of dollar outlays have been made comparable by the application of discount rates to the costs of each year. In order to simplify the analysis, it has been customary practice to assume, in the absence of strong evidence to the contrary, that all prices, costs, and incomes inflat or deflate at the same rate. Agencies of the Federal government, including the military services, are required to use a discount rate of 10% to evaluate government investments. The Office of Management and Budget Circular No. A-94, of March 1972, gives concise, useful guidance on applying the discounting principle. NAVFAC Manual P-442 and NAVFAC Instruction 4100.6 provide additional information on the latest fuel inflation factors that must be considered in life-cycle costing analysis. The 10% discount rate does not apply to certain buy-or-lease or make-or-buy decisions.

g. Maintenance Costs

Generally speaking, most solar energy system studies indicate maintenance costs for a solar water heater are minimal. A general rule-of-thumb calculation for figuring maintenance costs that most experts use is about 2% per year of the initial investment.

h. Miscellaneous Costs

May include costs such as for repairs, replacement, insurance, taxes, and salvage value, net of removal and disposal costs, if applicable. Insurance and taxes are normally not applicable to Navy investment costs in any case.

4. Determination of Amounts and Timing of Cash Flows

After selection of the alternatives and identification of the relevant costs for each alternative, the next step in the analysis is to determine the amount and timing of positive and negative cash flows associated with each alternative. The costs and their time of occurrence can be conveniently summarized by using cash flow diagrams, or as we shall see later, adapting computer programs for this purpose. It is necessary to take account of the timing of cash flows because money has a time value and must be discounted as appropriate at the discount rate selected.

5. Calculation of Life-Cycle Costs

This is the most important step in the analysis. Life-cycle costs of a solar water heater can be computed by either the present value or annual cost model. Both approaches take into account the changing real value of money over time. In the present value model, all costs and salvage values are forecasted over the period of analysis and then discounted to an equivalent single cost in today's dollars. In the annual cost model all costs and salvage values are forecasted

over the period of the analysis and then divided into uniform annual costs by discounting. Present value costs can easily be converted to an annual cost basis, and visa versa.* A look at the life-cycle present value model will be presented in the next section of this chapter.

6. Comparison of Costs for Alternatives

The last step in the analysis process is the comparison of costs of the alternatives. Several approaches to this process may be used. One is to calculate the life-cycle costs of each system with either the Net Present Value (NPV) or Net Annual Value (NAV) formula depicted in the next section. Then, the cost difference between the systems may be compared. This method identifies the system with the lowest life-cycle cost. There are numerous other methods which may also be used in analyzing investment decision, such as benefit-cost analysis, internal rate of return or yield method, simple pay-back method, and return-on-investment method.** However the life-cycle cost method is the one method felt best suited to Navy solar energy investments.

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*For additional information and explanation on these methods of investment analysis, the following sources are recommended: Smith, G. W., Engineering Economy: Analysis of Capital Expenditures, 2nd Edition, The Iowa State University Press, 1973; and Grant, E. L. and Ireson, W. G., Principles of Engineering Economy, 5th Edition, The Ronald Press Company, 1970.

**Ibid.

F. LIFE-CYCLE EVALUATION MODEL LOGIC

Apart from taxes, which are not utilized in life-cycle costing equations applications in Government investments, the basic equation for computing Net Present Value (NPV) of a solar-water heating system can be developed by applying to the basic cost items the appropriate inflation and discounting rates obtained from Appendix E. The following equation includes terms for basic costs and is suitable for computation of the costs of a conventional system as well as the solar water heating system.

$$NPV = I - \frac{S}{(1 + i)} + \sum_{j=1}^{N} \frac{(R_j - \overline{S}_j)}{(1 + i)^j} + M \frac{(1 + i)^N - 1}{i(1 + i)^N}$$

$$+ F_o \sum_{j=1}^{N} \frac{(1 + e_o)^j}{(1 + i)^j} + F_1 \sum_{j=1}^{N} \frac{(1 + e_1)^j}{(1 + i)^j} + B + Q$$

Net Present Value Equation [Ref. 35] (1)

where,

NPV = Net Present Value cost of the system over period N,

I = initial investment costs, including costs of delivery, acquisition, and installation of the system,

S = remaining value of the system at the end of the period of analysis,

i = annual discount rate in real terms,

N = period of analysis in years (may be the life of the building or a shorter designated period),

R_j = replacement and repair costs in year j at present prices, including costs of replacing or repairing any part of the system,

$\bar{S}_j$ = salvage value in year j, where $j=N$, at present prices, of replaced parts,

$R_j - \bar{S}_j$ = net replacement and repair costs in year j,

M = estimated annual maintenance cost at present prices, assumed here to be constant over the life of the system. (Alternatively, these costs might be assumed variable from year to year, in which case they could be included in the repair and replacement term; or they might be assumed to escalate at a constant rate or amount of time, in which case they could be treated as fuel costs are treated above or discounted by use of gradient series interest formulas, respectively.)

$\sum$ = summation sign (the sum of all the terms $j = 1$ to N),

F = estimated annual energy cost at present prices; subscripts indicate different sources of energy, e.g., F_o might indicate #2 heating oil and F_1 electricity,

e = annual rate of change in real price of energy, where subscripts indicate different sources of energy,

B = initial investment costs for the system -- related building modifications (if modifications are cost-reducing, B will be subtracted from costs),

Q = value of building space occupied by the system and components, evaluated as building cost per square foot times number square foot occupied.

Investment costs are entered in the equation without discounting, because these costs, as first costs, are already in present value terms. The remaining salvage value of the system, when use is terminated or the defined period has ended, is converted to present value by use of the single present worth formula, and is deducted from the investment cost because it represents investment costs not actually incurred. The cost of replacing parts of the system, net of the salvage value of the

old parts, are discounted from the year they are expected to be incurred to present value, summed, and added to other costs. Annual maintenance and repair costs might generally be assumed constant in real terms, and, if so, should be discounted to present value by use of the uniform present value formula.

Two terms, F_0 and F_1, are included for energy costs to indicate that several sources of energy of varying price might be used. The annual expenditure on each energy source should also be escalated if real increases in price are expected. The escalated annual costs are then discounted to its present value and then summed. The last two terms, B and Q, cost of building modifications and cost of building space occupied, are incurred initially, and, therefore, are already in present value equivalents.

The basic cost elements in the Net Annual Cost (NAC) equation illustrated below, are identical to those shown in the net present value equation. The only difference is in the discounting procedures. There are several ways to calculate the annual cost equation. One, is to apply a capital recovery factor to the Present Value Costs expressed in equation (1) to convert them to an equivalent uniform stream. This is essentially what has been done in equation (2) below, with the exception that annual maintenance cost, M, is entered directly, without discounting, since it is already in the appropriate form.

$$NAC = \left[I - \frac{S}{(1+i)^N} + \sum_{j=1}^{N} \frac{(R_j - \overline{S}_j)}{(1+i)^j} + F_1 \sum_{j=1}^{N} \frac{(1+e_o)^j}{(1+i)^j} + F_1 \sum_{j=1}^{N} \frac{(1+e_1)^j}{(1+i)^j} + B + Q \right] \times \left[\frac{i(1+i)^N}{(1+i)^N - 1} \right] + M,$$

<u>Net Annual Cost Equation</u> [Ref. 35]. (2)

where, the variables are as previously defined, except

NAC = Net Annual Cost of the system over period N.

APPENDIX C

LIFE-CYCLE COMPUTER SIMULATION PROGRAMS

There are several computer simulation programs that have been written to exercise the life-cycle model. Some of the more popular programs are the BASIC Language Model, F-Chart Calculation Model, and SOLCOST Calculation Model. Because of their universal application to solar energy systems in both the Federal and Civilian Sectors, they will be discussed briefly below for informational purposes.

A. BASIC LANGUAGE MODEL*

The BASIC Language Model is an algebraic programming language that allows the user to submit a program in a time-sharing environment, in ordinary mathematical notation. The format is designed to allow the analyst running the program on a teletypewriter terminal maximum flexibility in specifying the values of the critical parameters. The following parameters are entered in the program as "input statements": (1) the size of the collector; (2) the collector price per square foot; (3) the fixed and variable costs of non-collector components; (4) the

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*"BASIC" is the acronym for Beginners All-purpose Symbolic Instruction Code. For a description of the use of BASIC, see BASIC LANGUAGE, Honeywell Software Series 400, Honeywell Information Systems, Inc., August 1971.

heating load of the residence or building; (5) the expected performance of the solar system in terms of the percentage of the load provided; (6) the time horizon of the analysis; (7) the discount rate; (8) the current price of fuel and its expected future rate of increase; and (9) additional factors applicable to the civilian economy, such as interest rates for a mortgage, the property, sales and income tax incentives, and other special Federal and State government incentives presently being offered in a number of states.

In BASIC, the statement allows the person running the program to supply data for parameters through the teletypewriter keyboard while at the same time running the program. This format also allows parameters to be changed in successive runs to fit any particular circumstances. Although it does provide some flexibility, the extensive use of input statements makes the program execution extremely tedious in making a large number of program runs. If some of the input values will remain relatively constant throughout a number of successive runs, it might be advantageous to modify the program to change those particular input statements to "data statements," in order to have the data entered automatically.

B. F-CHART CALCULATION MODEL*

The F-chart program is written in standard FORTRAN II for use in the interactive mode. It can also be written in a batch mode but this is not very convenient.

The F-Chart Calculation Model treats the collector area as the main design variable, but includes means for taking into account secondary variables such as storage unit capacity, etc. It is basically a "quick design" method for solar heating systems, based on standard system configurations, using either liquid or air as the heat transfer medium. This method is referred to in short as the "F-Chart Method." It has proven useful for both design and economic studies.

Selecting the optimum collector size for a solar water heater is a matter of studying the interaction between the physics and economics of the system. The F-Chart method can help bridge these two areas. Its utility has led to the development of an interactive program which will give the thermal and economic performance of the system. There are two options available in the use of the program. One, the collector area can be specified and the annual (and/or monthly if desired) performance is returned. In addition, if cost data are supplied, an

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*The F-Chart Method was developed by the Solar Energy Laboratory of the University of Wisconsin. For additional information on this method refer to "A Design Procedure for Solar Heating Systems," by S. A. Klein, W. A. Beckman, and J. A. Duffie, Solar Energy, v. 118, Solar Energy Laboratory, University, Madison, Wisconsin, 1976.

economic assessment can also be furnished. Two, the program can find the economic optimum collector area by calculating the present value of future costs of the solar system and of the conventional fuel system, and if desired, the effects of escalating fuel prices, inflation, maintenance, depreciation, property and income taxes, tax rebates, etc. The optimum collector size, for the purpose of the F-Chart method, is that which minimizes the sum of the present value of future costs plus the initial cost of the solar energy system above the cost of a conventional energy system. The Solar Energy Laboratory at the University of Wisconsin will make the program available to interested persons. There is a charge of one-hundred dollars ($100.00) for a card deck (2,000 cards) or a punched paper tape, a program listing, data for over 100 different stations, and the paper describing the operation of the program. [Ref. 103].

C. SOLCOST CALCULATION MODEL*

The SOLCOST Calculation Model is a computer program developed by Martin Marietta Aerospace Corporation which is intended for use by architects, contractors, engineers and other members of the heating, ventilation and air conditioning industry responsible for

*The SOLCOST Method was performed under ERDA contract, "Solar Heating and Cooling Computer Analysis," EY-76-C-02-2876, formally E(11-1)-2876, by R. K. McMordie, C. L. Jensen, and R. T. Giellis, Martin Marietta Aerospace Corporation, Denver, Colorado, 1976.

making decisions on economically justifiable investments in solar heating and cooling systems, including water heating. The input data requirements have been simplified so non-thermal specialists can easily use SOLCOST to generate thermal performance and the resulting pay-back rate, or rate of return, for the proposed solar energy system.

The SOLCOST program computes an optimum solar collector size and tilt angle from an analysis of life-cycle cost differences for the solar system versus a conventional system. The basic approach used is to perform one-day-long computations for each month of the year. This computation utilizes historical weather data including maximum temperatures, minimum temperatures, average degree days, and percent sunshine values. It is the opinion of the authors of SOLCOST that it provides an accurate solution while keeping computer costs at a reasonable level. For the SOLCOST domestic hot-water load calculations, the user has a choice of entering his own domestic hot water heating load directly (in Btus per day) or using any one of three methods available in SOLCOST. In addition to water heating, several other types of solar systems can be evaluated with SOLCOST: (1) space heating and cooling with air or liquid collectors; (2) absorption cycle air conditioning systems; and (3) solar assisted heat pump systems.

In support of the SOLCOST calculation model, ERDA provides people anywhere in the U.S. with computerized findings about the costs of solar water heaters in individual homes. What you do is fill out a form (obtained from ERDA) about your residence, hot water needs and type of system you are considering. Send the form to the U.S. Energy Research and Development Administration (ERDA), SOLCOST, Division of Solar Energy, Washington, D.C. 20545. The form and a booklet explaining the program are free from ERDA. The information on your residence will be fed into a computer along with other data such as the amount of sunshine insolation in your area. You'll get back recommendations on the particular system you need, plus estimates of the cost of solar hot water for your residence compared with the cost of conventional fuels. In most places, there will be a charge for the services of between $10 and $20. However, individuals who apply for the $400 solar energy grant being offered by the Federal government in certain portions of the country, can obtain the ERDA computer service free of charge. [Ref. 69].

For additional information on this new simplified design method, for residential and light commercial solar heating and cooling as well as solar service hot water systems, contact:

International Business Services, Inc.
Solar Group
1010 Vermont Avenue
Washington, D.C. 20005
Telephone: (202) 628-1450.

APPENDIX D

SOLAR RADIATION INTENSITIES

Average Solar Radiation Intensities
Langleys/Day (Horizontal Surface)

Radiation Data From	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Annette, AK	63	113	231	360	457	466	481	352	266	122	59	40	251
Page, AZ	294	367	516	618	695	707	680	596	516	402	310	243	495
Yuma, AZ	305	401	517	633	703	705	652	587	530	442	330	271	506
Davis, CA	158	256	402	528	636	702	690	611	498	348	216	148	433
Fresno, CA	186	296	438	545	637	697	668	606	503	375	241	160	446
Inyokern, CA	312	419	578	701	789	836	784	738	648	484	366	295	579
Los Angeles, CA	243	337	446	518	517	594	645	579	505	365	277	228	442
Pasadena, CA	251	333	439	509	569	580	634	599	482	366	271	236	439
Riverside, CA	271	362	468	526	608	666	652	603	521	400	309	260	470
San Diego, CA	265	343	428	464	493	510	547	499	446	361	284	245	407
Washington, DC	159	230	320	403	447	558	529	462	367	281	211	147	343
Gainesville, FL	278	367	445	539	586	544	520	508	444	368	318	254	431
Jacksonville, FL	267	346	423	514	556	525	522	476	383	331	274	230	404
Key West, FL	327	410	490	572	579	543	534	501	445	394	332	292	452
Miami, FL	343	416	491	544	552	531	537	508	447	389	354	319	453
Pensacola, FL	250	321	405	509	562	568	537	509	430	394	278	224	416
Tallahassee, FL	274	311	423	483	548	476	544	537	424	353	364	260	416
Atlanta, GA	228	284	377	484	535	554	538	502	412	350	265	201	394
Griffin, GA	238	302	388	519	577	580	559	523	437	372	288	210	416
Pearl Harbor, HI	355	404	438	536	577	562	610	575	536	466	393	349	483
Lemont, IL	171	232	326	390	497	553	527	486	384	265	157	131	343
Indianapolis, IN	147	214	312	393	491	547	542	486	405	293	176	130	345
Louisville, KY	164	231	325	420	515	560	550	498	408	303	190	150	360
Lake Charles, LA	239	304	396	483	554	582	521	506	448	402	296	232	414
New Orleans, LA	237	296	393	479	539	549	502	491	418	389	269	220	399
Boston, MA	139	198	293	364	472	499	496	425	341	238	145	119	311
Portland, ME	157	237	359	406	513	541	561	482	383	273	157	138	351
Annapolis, MD	175	243	340	419	488	557	542	469	383	294	189	155	355
Silver Hill, MD	182	244	340	438	513	555	516	459	397	295	202	163	359
St. Cloud, MN	170	251	366	423	499	541	555	491	360	241	146	123	348
Cape Hatteras, NC	244	317	432	571	635	645	629	557	472	361	284	216	447
Sea Brook, NJ	157	227	318	403	478	522	518	457	385	285	192	139	340
Trenton, NJ	173	244	343	424	491	546	540	469	389	294	195	155	355
Ely, NV	238	333	464	564	624	708	648	608	519	393	287	220	467
Reno, NV	234	324	449	592	664	714	707	646	532	395	277	209	479
New York, NY	146	210	312	378	455	526	518	492	361	262	160	128	324
Oklahoma City, OK	255	317	407	498	540	623	610	588	484	379	284	237	435
Philadelphia, PA	175	242	347	425	493	554	538	465	388	293	191	152	355
State College, PA	139	202	297	373	467	544	528	454	361	275	155	120	335
Newport, RI	115	231	330	395	489	538	517	449	380	273	175	141	339
Charleston, SC	250	308	393	517	553	556	523	495	417	349	281	228	406
Nashville, TN	163	240	329	450	517	567	553	494	428	327	217	161	370
Brownsville, TX	287	336	402	458	556	604	619	555	465	406	284	253	435
Corpus Cristi, TX	262	330	413	474	561	604	629	558	470	408	285	240	436
Dallas, TX	231	307	394	454	521	595	588	538	458	363	261	221	411
El Paso, TX	331	432	549	655	715	730	670	639	575	462	367	313	536
Norfolk, VA	208	270	372	477	540	572	550	481	398	310	223	184	382
Seattle, WA	70	124	244	360	446	471	501	431	310	174	90	59	273
Albrook A. B. Panama	392	476	525	499	404	336	370	372	448	338	380	420	426
Wake Island	438	518	570	623	644	648	636	623	587	530	485	399	558
San Juan, P. R.	429	489	581	607	555	612	643	574	542	495	428	428	532
Taipei, Taiwan	186	216	261	312	381	393	400	412	341	340	296	225	314

(Source: NAVFAC Technical Report R-835, Ref. 36).

APPENDIX E

ANNUAL FUEL INFLATION FACTORS

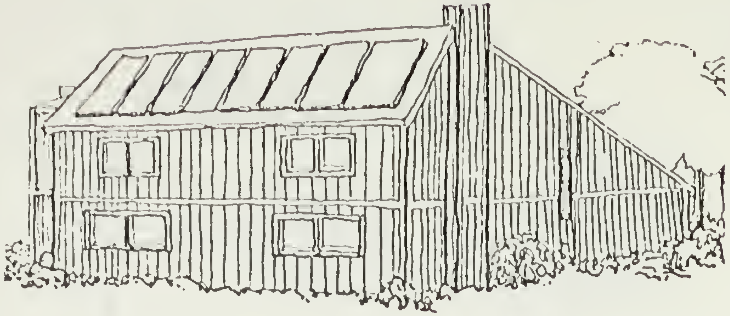
Example Year	Coal and Gas		Oil		Electric	
	7% Inflation 10% Discount		9% Inflation 10% Discount		3% Inflation 10% Discount	
	Single Amount	Cumulative Series	Single Amount	Cumulative Series	Single Amount	Cumulative Series
1	0.986	0.986	0.995	0.995	0.968	0.968
2	0.959	1.946	0.986	1.982	0.906	1.874
3	0.933	2.879	0.977	2.959	0.849	2.723
4	0.908	3.787	0.969	3.928	0.795	3.517
5	0.883	4.670	0.960	4.887	0.744	4.261
6	0.859	5.529	0.951	5.839	0.697	4.958
7	0.836	6.364	0.942	6.781	0.652	5.610
8	0.813	7.177	0.934	7.715	0.611	6.221
9	0.791	7.968	0.925	8.640	0.572	6.793
10	0.769	8.737	0.917	9.557	0.536	7.329
11	0.748	9.485	0.909	10.465	0.501	7.830
12	0.728	10.212	0.900	11.366	0.470	8.300
13	0.708	10.920	0.892	12.258	0.440	8.739
14	0.688	11.608	0.884	13.142	0.412	9.151
15	0.670	12.278	0.876	14.018	0.386	9.536

Notes: Consult NAVFAC INSTR 4100.6 for latest fuel inflation factors.
Consult NAVFAC Manual P-442 for Compound Amount Factor tables for inflation rates not given.
(Source: NAVFAC Tech. Report R-835, January 1976, Ref. 36)

APPENDIX F

SAMPLE SOLAR SYSTEM INFORMATION

VIRGINIA | 4224 DD | 1 SFD NEW | ACTIVE HEATING | 1



PROJECT INFORMATION:
BUILDER/APPLICANT: J&J Construction Co.
DESIGNER: Westinghouse Electric Corp.
SOLAR SUB: Westinghouse Electric Corp
LOCATION: Dumfries, VA
HOUSING TYPE: SFD, 1 Unit
CLIMATIC DATA:
HEATING DD: 4,224
DESIGN TEMP: WINTER: 16° F
HORIZ. INSOL. JAN DAY: 720 BTU/ft²

LATITUDE: 38 5°N
AREA: 1,632 sq. ft./unit
COOLING HRS:
SUMMER:
% SUN/YR: 58%

BUILDING DESCRIPTION/ENERGY CONCERNS

This new single family detached unit incorporates 1,632 sq. ft. with 3 bedrooms. Energy conservation features include minimal windows on the east and west elevations; double insulating glass in windows on the northern face and a garage located on the northwest corner to act as a thermal buffer. In addition, 3" of rigid insulation under a sheathing of blanket insulation is used in the walls and ceiling. Exterior doors are steel with integral weatherstripping

SOLAR ENERGY SYSTEM: ACTIVE
SOLAR APPLICATION: Heating
PREDICTED SOLAR CONTRIBUTION: 52%

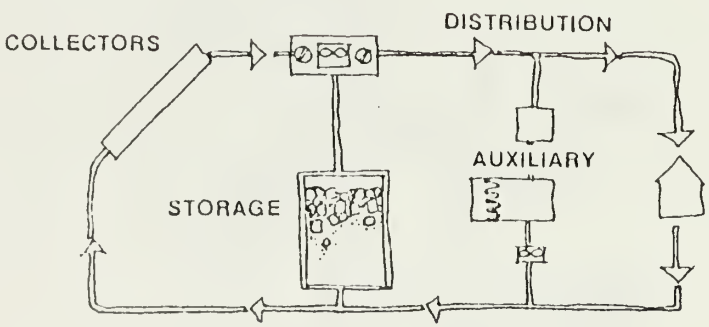
COLLECTOR: 205 sq. ft. of Sunworks/Solector, flat plate air collectors are located on the roof of the building at a 60° tilt. The building is oriented so that panels face south and are mounted with standoff framing. A collector fan transfers heated air to rock storage.

STORAGE: 400 cu. ft. of rock acts as heat storage in a bin constructed from concrete block with 1" foam insulation.

DISTRIBUTION: Heated air is blown either from rock storage to the living space, or directly drawn from the collector to the living space.

AUXILIARY ENERGY SYSTEM: An electric heat pump, with a coil located in the air ducts, heats the air supply to the living space.

MODES OF OPERATION: Collector to house, collector to storage, storage to house, auxiliary to house.



(Source: Ref. 71)

GEORGIA

2961 DD

3 SFD NEW

ACTIVE HEATING & DHW

7

PROJECT INFORMATION:

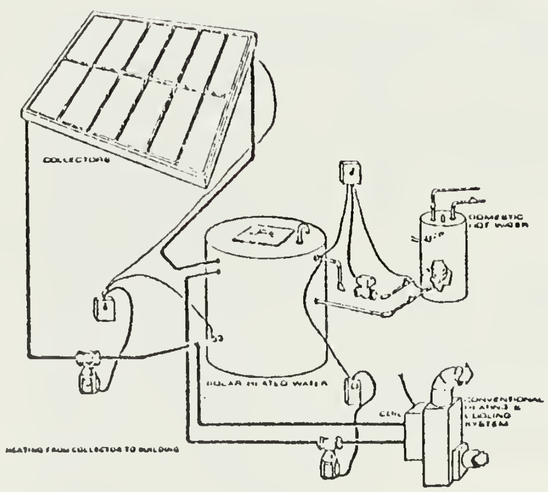
BUILDER/APPLICANT: Fairview Builders
DESIGNER: Winford Lindsay, Arch.
SOLAR SUB: Independent Living, Inc.
LOCATION: Lawrenceville, GA
HOUSING TYPE: SFD, 3 Units
CLIMATIC DATA:
HEATING DD: 2,961
DESIGN TEMP. WINTER: 20° F
HORIZ. INSOL. JAN DAY: 806 BTU/ft²

LATITUDE: 33.4°N
AREA: 1,000 sq. ft.

COOLING HRS:
SUMMER:
% SUN/YR: 60%

BUILDING DESCRIPTION/ENERGY CONCERNS

This project involves 3 new single family detached homes of 1,000 sq. ft. each, with different floor plans and price tags. One passive design concern includes overhangs on the south wall to reduce heat gain in summer.



(Source: Ref. 71)

SOLAR ENERGY SYSTEM: ACTIVE

SOLAR APPLICATION: Heating & Domestic Hot Water
PREDICTED SOLAR CONTRIBUTION: 75.4%

COLLECTOR: 234 sq. ft. of flat plate collector, manufactured by Revere, is integrated with the structure on the roof of each unit. The tilt is 45° on the south facing roof slope. Water is used to transfer heat to liquid storage.

STORAGE: A 1,000 gallon steel water storage tank is located in the basement of the unit. The heated water is pumped from storage through a heat exchange coil in the air duct.

DISTRIBUTION: Forced air conventional system.

AUXILIARY ENERGY SYSTEM: A conventional gas-fired furnace with a capacity of 18,000 BTUH heats the air in the ducts as backup energy.

DOMESTIC HOT WATER: A closed loop from the storage tank channels hot water through a preheat coil in the conventional hot water heater.

MODES OF OPERATION: Collector to storage, storage to house, auxiliary to house, DHW preheat.

52

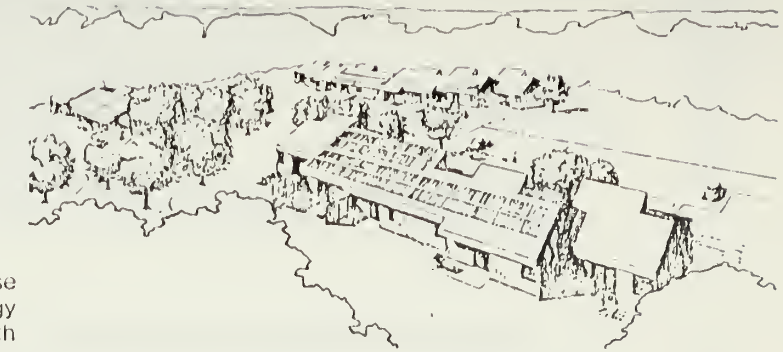
ACTIVE H, C, & DHW   18 SFA NEW   3393 DD   N. CAROLINA

PROJECT INFORMATION:
BUILDER/APPLICANT: Durham Housing Authority
DESIGNER: John F Latimer & Associates, Inc.
SOLAR SUB:

LOCATION: Durham, N C.	LATITUDE: 36°N
HOUSING TYPE: SFA, 18 Units	AREA: 519-730 sq. ft.
CLIMATIC DATA:	
HEATING DD 3,393	COOLING HRS: 750
DESIGN TEMP. WINTER. 15°F	SUMMER 92° F
HORIZ. INSOL. JAN DAY: 850 BTU/FT²	% SUN/YR. 61%

BUILDING DESCRIPTION/ENERGY CONCERNS

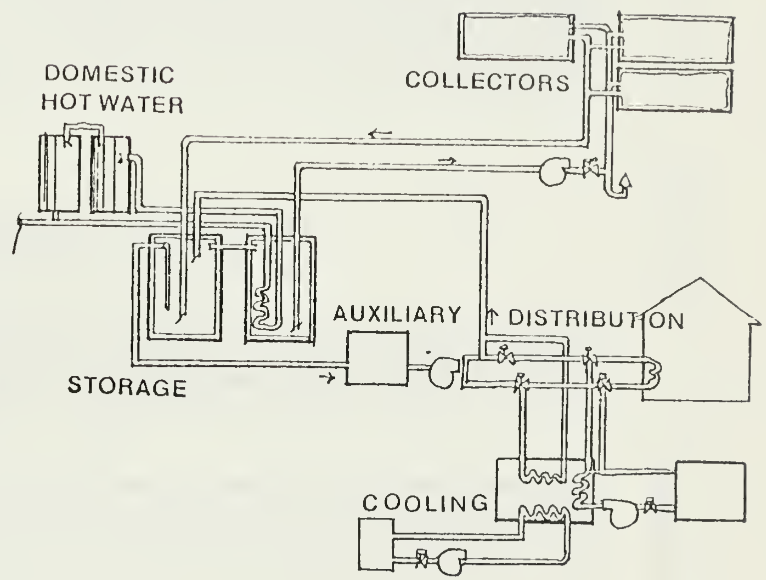
This project has 18 units of three types with 4 to 6 units per townhouse grouping. Each unit encompasses 519 to 730 sq. ft. of space. Energy conservation features include minimum window openings on the north face, no openings on the east and west faces, and overhangs on the south face. Clerestories are placed facing north to minimize summer heat gain, while the roof itself is heavily insulated against heat transfer.



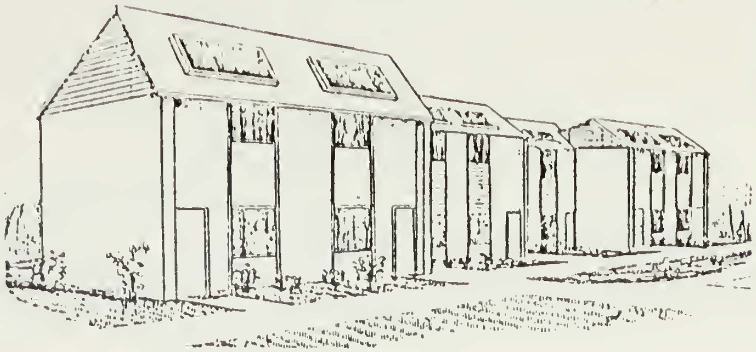
SOLAR ENERGY SYSTEM: ACTIVE

SOLAR APPLICATION: Heating, Cooling & Domestic Hot Water
PREDICTED SOLAR CONTRIBUTION: 79%

COLLECTOR: 166 sq. ft. of evacuated tube liquid collectors are standoff mounted to the south facing roofs at a 30° tilt. Manufactured by Owens-Illinois, these collectors use water to transfer the sun's heat to water storage. When necessary, antifreeze is added to prevent freezing.
STORAGE: 6,000 gallons of water are located centrally in 2 tanks per townhouse grouping. The tanks are phenol lined steel with 3" of styrofoam insulation. From here, water is pumped to local fan coil units, and heated air is blown into the space.
DISTRIBUTION: A hydronic system to each fan coil unit is combined with forced air distribution.
AUXILIARY ENERGY SYSTEM: A gas fired boiler of 400,000 BTUH capacity is used as backup for the heating & absorption chiller systems.
DOMESTIC HOT WATER: City water is preheated in a copper heat exchange coil located in solar storage. From here water is circulated to one of 2 conventional gas-fired 100-gallon domestic hot water heaters located in the utility room of each townhouse group.
COOLING: Cooling is provided by Arkla absorption chillers combined with a cooling tower. This operates with high temperature heat from the evacuated tube collectors.
MODES OF OPERATION: Collector to storage, storage to house, storage to auxiliary to house, auxiliary to house, DHW preheat, cooling.



(Source: Ref. 71)



PROJECT INFORMATION:
BUILDER/APPLICANT: Dalton Housing Authority
DESIGNER: Associated Architects, Inc.
SOLAR SUB: Solar Development Inc.
LOCATION: Dalton, GA
HOUSING TYPE: SFA, 12 Units
CLIMATIC DATA:
HEATING DD: 3,254
DESIGN TEMP WINTER: 43° F
HORIZ. INSOL. JAN DAY: 730 BTU/ft²

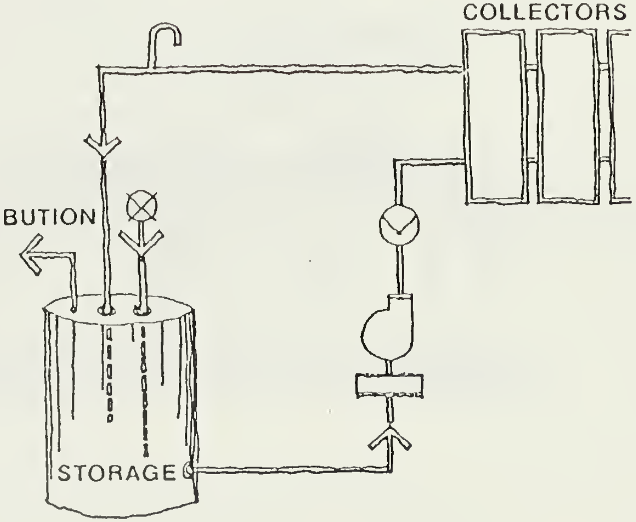
LATITUDE: 34°5'N
AREA: 884 sq ft./unit

COOLING HRS:
SUMMER: 80° F
% SUN/YR. 70%

GEORGIA

BUILDING DESCRIPTION/ENERGY CONCERNS
These 12 units of new 2 bedroom townhouses include several construction features for energy conservation. The houses, a compact 884 sq ft. each, face north and south, while east and west facades are closed end walls or party walls. Wall insulation has been increased to 6" in thickness between 2x6 studs, 24" on center. Walls are sheathed in polystyrene and the floor slab perimeter is protected against heat loss by 2" of rigid insulation.

3254 DD



(Source: Ref. 71)

SOLAR ENERGY SYSTEM: ACTIVE
SOLAR APPLICATION: Domestic Hot Water
PREDICTED SOLAR CONTRIBUTION: 88%

12 SFA NEW

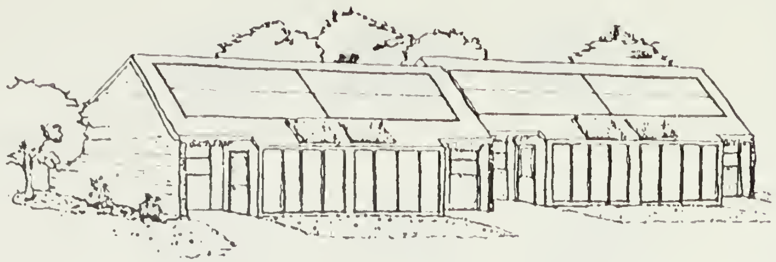
COLLECTOR: 720 sq ft. total (60 sq. ft. per unit) of flat plate liquid collectors have been direct mounted, south facing, at a 45° tilt on the roofs of the 12 attached units. Manufactured by Solar Development Inc., the system pumps city water directly through the collectors to preheat the domestic hot water supply.

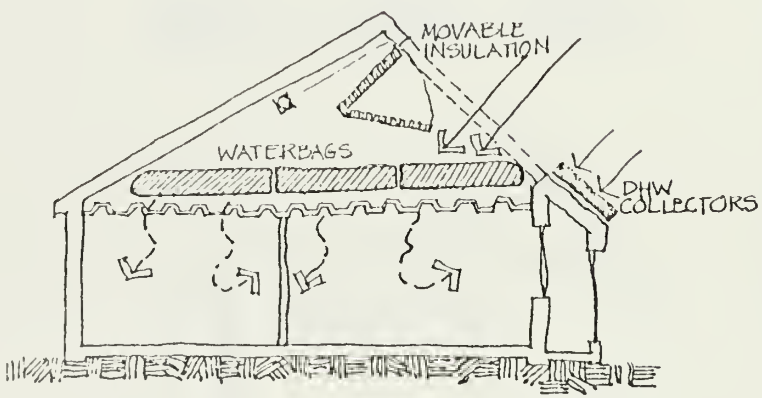
STORAGE: 52 gallons of water, contained in the insulated DHW heater in each unit, acts as both solar storage and conventional DHW storage. City water that has been heated in the collectors provides almost 100% of the DHW needs directly and is stored in the 52 gallon tank.

AUXILIARY ENERGY SYSTEM: An electric resistance heating element has been placed in the top of this DHW tank, can provide an auxiliary DHW capacity of 18,770 BTUH.

ACTIVE DHW

57





(Source: Ref. 71)

PROJECT INFORMATION:

BUILDER/APPLICANT: South Central Community Action Program, Inc.
DESIGNER: Associated Architects & Engineers
SOLAR SUB: Harold Hay/Skytherm
LOCATION: Lake Andes, SD
HOUSING TYPE: SFA, 4 Units
LATITUDE: 43°N
AREA: 540 sq. ft./unit
CLIMATIC DATA:
HEATING DD. 7,133
DESIGN TEMP. WINTER: −5° F
HORIZ. INSOL. JAN. DAY: 680 BTU/ft²
COOLING HRS:
SUMMER: 90° F
% SUN/YR: 59%

BUILDING DESCRIPTION/ENERGY CONCERNS

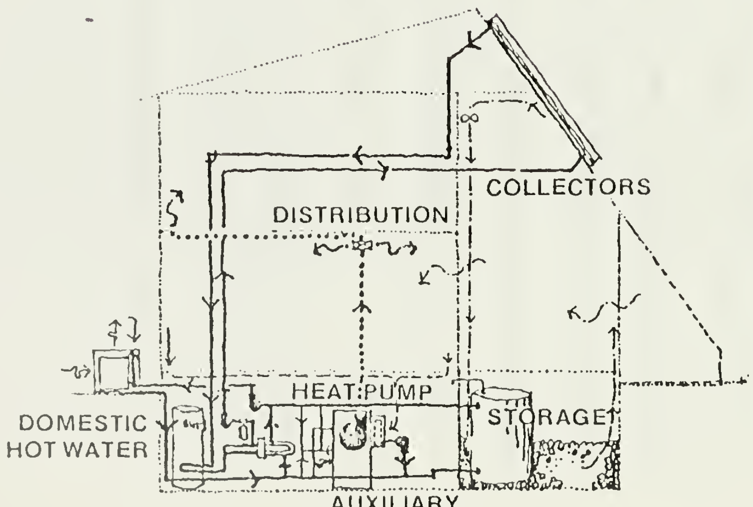
This project consists of 4 single family attached homes with approximately 600 sq. ft. of space in each unit. In order to conserve energy, the units are oriented to the south, therefore closing off east and west faces to summer heat gain and winter heat loss. The north face has only minimal openings and the plan is organized with living spaces to the south where there are maximum window openings. This, along with a greenhouse on the south (which acts as an entry air lock), optimizes winter heat gain.

SOLAR ENERGY SYSTEM: PASSIVE AND ACTIVE

SOLAR APPLICATION: Passive Heating & Active Domestic Hot Water
PREDICTED SOLAR CONTRIBUTION: 98%

PASSIVE SYSTEM: Skytherm "thermoponds", filled with water, are located in the attic of each unit. Opening the Movable insulation in the roof structure exposes the ponds to the sun. Later the roof panels can be closed in order to retain the heat during nighttime hours. The thermoponds then store heat and distribute it to the house via conduction and radiation through the ceiling. Auxiliary heat is provided by an electric heater in each unit with a capacity of 30,000 BTUH.

DOMESTIC HOT WATER: Solar heat for the DHW system is provided by 114 sq. ft. of collector located on the roof of the greenhouse, facing south at a 45° tilt.



(Source: Ref. 71)

PROJECT INFORMATION:

BUILDER/APPLICANT: Oscar P Wren
DESIGNER: Donald Watson
SOLAR SUB: Max Cochran
LOCATION: Tomaro Oaks, MO — LATITUDE: 37°N
HOUSING TYPE: SFD, 1 Unit — AREA: 1,304 sq. ft.
CLIMATIC DATA:
HEATING DD: 4,561 — COOLING HRS:
DESIGN TEMP WINTER: 15° F — SUMMER: 96° F
HORIZ. INSOL. JAN. DAY: 700 BTU/ft² — % SUN/YR. 63%

BUILDING DESCRIPTION/ENERGY CONCERNS

A greenhouse contributes heat to this single family home with 3 bedrooms and 1,304 sq. ft. This unit is one in a series of prefabricated homes. The living spaces are located on the south side of the house while services and equipment are grouped on the north, aiding in thermal optimization. Glass doors on the south wall are recessed to shade from the summer sun. North glazing is high to vent summer heat gain. Minimum openings on the east and west faces lessen summer heat gain and winter heat loss. Good insulation is used throughout, and the entry forms an airlock.

SOLAR ENERGY SYSTEM: HYBIRD

SOLAR APPLICATION: Passive & Active Heating, & Active DHW
PREDICTED SOLAR CONTRIBUTION: 77%

PASSIVE SYSTEM: Heat that has been collected in the greenhouse is drawn from the upper part of the sunroom by a fan and taken to the rock storage surrounding the active system water storage. Cooler air is returned to the sunroom below the south facing windows. When the sunroom is opened to the rest of the house, radiant and convective heat is provided directly to the interior spaces.

ACTIVE SYSTEM: 223 sq. ft. of flat plate collectors are located on the roof facing 20° east of south at a 54° tilt. The collectors are manufactured by Sunworks. The liquid system uses propylene glycol as a transfer fluid which passes through a heat exchanger to transfer the collected heat to water storage. The storage is a 1,000 gal. water tank which sits in a rock bed under the house. In the summer, this storage combines with a heat pump to provide chilled water storage for the cooling system. To heat the living space from storage, a forced air system distributes the collected heat by passing air over a hot coil containing heated water from storage. This coil is located in the return air duct. Auxiliary heat source is a heat pump in the basement with a capacity of 44,500 BTUH.

DOMESTIC HOT WATER: In order to preheat domestic hot water, heated water from the collectors passes through a coil in the 65 gal. conventional electric hot water tank.

APPENDIX G

SOLAR SPACE HEATING AND WATER HEATING RESULTS

During the past few years, there have been several test projects initiated and completed involving solar space heating and water heating applications supporting findings that space heating and water heating are economically attractive at the present time in many parts of the U.S. There are other studies which contradict this finding. A brief summary of the results of several of these projects is included below for informational purposes.

A. NATIONAL SCIENCE FOUNDATION STUDY

The primary result of the National Science Foundation study is a twenty U.S. city cost comparison of solar space and hot water heating (combined) with conventional space and hot water heating in detached residences. Geographical variations in conventional fuel costs and solar heating system performance are considered, although the geographical variations in solar equipment and installation costs are neglected. Solar equipment annual performance estimates for each city are obtained by combining climatic data with equipment characteristics as input to a simulation model developed at the University of Wisconsin. The assessment report also contains a section on

life-cycle cost analysis and one on the economic feasibility of solar heating in the 20 U.S. cities. [Ref. 5].

B. MITRE CORPORATION STUDY

The MITRE Corporation Study conducted for the National Science Foundation is one of a series of four reports that cover a MITRE Corporation study of the NSF Five-Year Solar Energy Research Program. The approach used in this part of the study includes the following: define general program structure, identify and describe current state-of-the-art, assess currently studied systems, identify problems, formulate comprehensive set of research tasks, identify proof-of-concept experiments, and describe scenarios for production and implementation. According to the study, a total of between 20 and 35 percent of the U.S. energy requirements might be supplied from solar energy by the year 2000. By the year 2020 this figure could be as much as 70 percent, although that degree of substitution for fossil fuel and nuclear fuels is extremely doubtful. The main conclusion that can be drawn from the study is that all of the solar energy systems, under construction by NSF, appear worthy of further RD&D at the present time. [Ref. 21].

C. ERDA ECONOMIC ANALYSIS OF SOLAR WATER AND SPACE HEATING

The main conclusion drawn from the ERDA Economic Analysis study is that based on comparison with conventional energy costs,

solar water and space heating installed at an equivalent system cost of $20 per square foot of collector is competitive today against electric resistance systems throughout most of the U.S. If the system cost is reduced to $15 per square foot, solar systems become competitive against oil hot water heating and/or electric heat pump space heating in many cities. Finally, if the cost should be reduced to $10 per square foot by 1980 through combination of technical innovations and incentives, solar hot water and heat would be economically competitive against all residential fuel types. The system designs were performed using the design program (F-Chart) developed by the University of Wisconsin and modified by MITRE Corporation. [Ref. 32].

D. U. S. AIR FORCE ACADEMY HOUSING RETROFIT

The U.S. Air Force Academy Housing Retrofit Project titled Solar Heating Retrofit of Military Family Housing is the current major project within the Air Force Academy Solar Energy Program. The interim technical report describes the programming, facility, acquisition, and initial performance of the first retrofit constructed solar-heated facility in the U.S. Air Force, the Solar Test House at the U.S. Air Force Academy. Several key conclusions reached during the testing are:

1. It appears all necessary solar energy system hardware components are commercially available today.

2. Because of the large capital cost associated with solar energy systems, additional work in control systems would be very beneficial.

3. In a competitive economic environment with conventional fossil fuels, solar energy presently falls somewhat short, especially in the case of single applications to single family residential dwellings. The combination of high capital costs and low conventional fuel costs account for this general observation.

4. Multi-unit, large-scale applications in some parts of the U.S., especially of the new construction category, can probably be shown to be cost effective. Perhaps a cluster concept with one solar collector bank serving a number of single family dwellings would also have merit at this time.

5. Although solar energy systems are not completely cost effective in the private sector at this time, it may be that they offer distinct and immediate military applications. For example, the ground array used in this project could easily be used at remote sites for space heating and in contingency areas. The ground array is capable of being moderately prefabricated, can be relocated and can be made air transportable.

6. Maintenance on the ground array was easier to perform than on the roof array. No solar collector damage attributable to either adverse weather or vandalism was observed on either the ground or roof arrays.

7. Storage tank size, with respect to the rest of the solar energy system, has the most significant impact on both the system heating efficiency as well as on the system collection efficiency.

8. Based on the promising results of this project to date, the Air Force should continue to pursue field scale, real property oriented solar energy applications. [Ref. 66].

E. U. S. AIR FORCE ENERGY CONSERVATION HANDBOOK

Three sections of the new five-part Air Force Conservation Handbook, prepared by the National Bureau of Standards, contain information and guidance pertinent to many Navy activities. The handbook focuses on the needs of energy managers and base level technical personnel. Since military services, in general, have similar energy conservation and retrofit problems, the first three sections may be used effectively within the Navy. These three sections dealing with "conservation" and "retrofit" applications are as follows:

1. "An Approach for Managing an Energy Conservation Program" (AFCEC-TR-77-11). It is written primarily for energy managers to enhance their understanding of energy conservation measures and to assist them develop comprehensive programs.

2. "Technical Guidelines for Energy Conservation in Existing Buildings" (AFCEC-TR-77-12). This section constitutes the major

part of the handbook and is primarily for base level technical personnel.

3. "Identifying Retrofit Projects for Federal Buildings" (FEA/D-76-467). This third "retrofit" part of the handbook is the Federal Energy Administration document.

Additional sections of the Handbook, titled "Domestic Hot Water Heating Systems," "Solar Collectors" and "Simplified Economic Analysis," deal with solar energy hot-water heating systems. The Handbook indicates that the heating of domestic hot water with solar energy is the most economically viable application and one that should be considered for all locations within the United States.

F. SOLAR ENERGY SYSTEMS FOR COAST GUARD PUBLIC QUARTERS

The Coast Guard report contains energy requirements for Coast Guard-owned public quarters which were assessed based on a survey of energy usage for Fiscal Year 1975. A computerized solar collector heat gain model was developed to identify regions in which solar heating might be cost beneficial under a conservative scenario and using generalized data. A region containing 45 structures (with 74 public quarters) at ten sites was identified. Energy requirements and regional insolation and weather data for each specific site were then used in the model to determine solar collector requirements and cost break-even periods. The baseline analysis identified gross

energy usage by buildings and facilities, cutters, aircraft, and vehicles, boats and equipment. It showed that approximately 42% of the total Coast Guard energy usage was accounted for by buildings and facilities in FY 75. Since a significant portion of the total Coast Guard energy consumption is used by public quarters, any conservation of energy usage in this area can make a significant contribution to the Coast Guard's conservation program. Based on the findings, a solar heating applications research project has been outlined in the report to capitalize on solar energy. [Ref. 110].

G. SOLAR WATER HEATING EXPERIMENT BY NEW ENGLAND ELECTRIC

In the first major field demonstration of solar water heaters in a freezing climate, New England Electric is testing commercially available solar water heaters in 100 single-family houses in Massachusetts, Rhode Island and New Hampshire. The project was started in December 1975 and is expected to run until September 1979. [Refs. 91, 92].

According to the Interim Report of the experiment prepared for New England Electric by Arthur D. Little, Inc., dated 17 May 1977, the program has identified many of the problems that will occur in the development of a solar energy industry and offers an opportunity for manufacturers, consumers, and government to understand and attempt to overcome these obstacles.

Interim findings indicate that:

"... Solar energy is a victim of unreasonably high expectations. Up to now, projections of cost and reliability have tended to be optimistic. There has been little recognition given to the fact that the solar water heater industry is in its infancy in northern climates and few manufacturers have experience with real-life installation problems. Under actual operating conditions in the field, solar hot water installations have encountered many of the same difficulties faced by other mechanical systems in the early years of product development. These problems must be resolved if solar water heaters are to become economically viable. [Ref. 92].

Key findings summarized in the Interim Report are:

1. Some specific design and operating problems have yet to be solved.

2. Properly designed and serviced systems operated satisfactorily. In general, energy savings were lowered by start-up problems.

3. First costs for installed systems were high.

4. Manufacturers/installers must assume responsibility for the successful operation of their systems.

5. Industry standards are urgently needed.

6. Buyers should exercise caution.

7. A great deal is being learned from this program. [Ref. 92].

Some specific design and operating problems evident in the experiment need to be resolved. Many operating problems developed during the experiment, and according to New England Electric they were predictable. They occurred because ... .

"... the majority of participating manufacturers and installers had little or no practical experience with solar water heaters and some had limited financial resources. Others were not wholeheartedly committed to the demonstration and did not respond when problems were reported.

Design and operating problems included inadequate pipe insulation, malfunctioning controls, and freeze-up, problems which can be resolved if manufacturers improve their component and installation specifications. [Ref. 92].

It was noted that properly designed and serviced systems operated satisfactorily. But, in general, energy savings were lowered by start-up problems. Due to the prevalance of design difficulties and malfunctions encountered in most installations, the overall average energy savings was under 20%. However, the 15 best systems reduced hot water heating energy consumption by an average of 37%, even during extremely severe weather conditions. At the other end of the spectrum, the 15 worst systems averaged less than 5%. [Ref. 92].

According to the Project Supervisor, John Meeker, earlier estimates of $1,000 to $1,700 for solar water heating systems actually ranged from $1,365 to $2,950 per unit. The actual cost of solar systems installed varied appreciably as shown in Table G-I.

The most common types of design problems, and an indication of the frequency with which they occurred in the various generic systems, is summarized in Figure G-1. In general, the major design problems were associated with cold weather design features, such as:

Table G-I. Actual Cost of Solar Systems Installed.

System Cost	No. of Systems	System Cost	No. of Systems
$1500-1600	8	$2201-2300	2
1601-1700	7	2301-2400	9
1701-1800	10	2401-2500	4
1801-1900	12	2501-2600	2
1901-2000	3	2601-2700	3
2001-2100	15	2701-2800	5
2101-2200	13	2801-3000	7

(Source: Ref. 92).

8. Failure of downdrain system to completely drain, frequently associated with liquid traps in uneven buried drain lines, and generally leading to freeze-up of lines and/or components.

9. Freeze-up in inadequately protected lines leading to closed cycle freezable collectors.

10. Leakage in antifreeze loops resulting in air locks when fluid inventory was reduced -- or to freeze-up if the system was automatically refilled with water.

11. High circulating power in some air systems apparently caused by the installation of unnecessarily large fans. [Ref. 92].

It must be recognized that these results are based on a limited number of manufacturers in an early stage of the industry and that subsequent design improvements may eliminate many of the problems

Design Problems by Generic System Type	Water Draindown	Closed Loop Water	Closed Loop Antifreeze	Air
Inadequate Insulation	F	F	F	F
Malfunctioning Controls	F	F	F	DNO
Freeze-up	F	F	RI	DNO
System Air Lock	RI	F	FI	DNO
Noisy Equipment	F	DNO	DNO	RI
High Circulating Power	FI	DNO	DNO	RI

Key:
F - Frequently
RI - Relatively Infrequent
DNO - Did Not Occur

Fig. G-1. Frequency Occurrence of Most Common Design Problems. (Source: Ref. 92)

which appear serious at this stage of the experiment. For example, the frequency of poorly insulated piping and malfunctioning controls will undoubtedly be reduced as manufacturers and contractors improve their installation and component specifications and construction techniques. To date, there have been no incidents reported relative to safety hazards and minimal problems associated with glass breakage. The Interim Report further indicates that system instrumentation designed and provided by the electric companies has been reasonably trouble-free and has been valuable in indicating the approximate energy savings and signaling system malfunctions. [Ref. 92].

H. NASA LANGLEY RESEARCH CENTER TECHNICAL MEMORANDUM

This technical memorandum concerning an inexpensive solar heating system for homes describes a low-cost solar home heating system to supplement the homeowner's present warm-air heating system. It is written in three parts:

1. A brief background on solar heating.
2. Langley's experience with a demonstration system.
3. Information for homeowner who wishes to construct such a system.

Instructions are given to the homeowner for a solar space and water heating installation in which he supplies all labor necessary to install off-the-shelf components estimated to cost about $2,000. This report gives performance data obtained from a demonstration system which has been built and tested at the Langley Research Center. The results of the tested demonstration system indicate that the homeowner can supplement his existing forced-warm-air heating system and reduce the heating bill by approximately 40% for a 1500-square-foot house insulated to 1974 FHA minimum standards. [Ref. 105].

I. DEFENSE ENERGY INITIATIVES TEN-YEAR SOLAR PROGRAM FOR NAVAL SHORE ESTABLISHMENT HOUSING UNITS

This study in response to a request by the Chief of Naval Operations, describes a proposed phased program to apply state-of-the-art solar equipment to Navy family housing as a major stimulus to the National

Solar Demonstration Program. The preliminary economic study indicates that the proposed retrofit solar systems -- solar assisted optimized heat pump (SAOHP) -- are currently economically attractive in all zones where electricity is the source of heating, water heating and air conditioning. Solar water heating, itself, appears economical in locations requiring air conditioning even where natural gas is used as a primary source of energy. The potential ten-year application of the solar systems proposed in the study to approximately 80,000 units of Navy family housing is estimated to be about $560 million, or about $7,000 per unit in 1976 dollars (Net Present Value -- NPV). The report describes examples of investment cost, potential payback timetables, and outlines technical design systems which could convert these 80,000 units of Navy and Marine Corps family housing to solar energy with a utilization of solar factor in excess of 60% of present energy use. [Ref. 40].

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